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Field Evaluation of the Movement of Agricultural Chemical Contaminants in Alluvial Soils With a Shallow Water Table.

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Field evaluation of the movement of agricultural chemical contaminants in alluvial soils with a shallow water table

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FIELD EVALUATION OF THE MOVEMENT OF AGRICULTURAL CHEMICAL CONTAMINANTS IN ALLUVIAL SOILS WITH A SHALLOW WATER TABLE

A Dissertation

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in

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by
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To Myla Rowena, Anna Ruth, and Czarina that they may soon realize the importance of research in the pursuit of their dreams;

And, to the Almighty whose graces are always abundant for those who believe.

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ABSTRACT

The movement of agricultural chemical contaminants in alluvial soils with a shallow water table in a warm, humid environment was evaluated in this study. Bromide, a non-adsorbent tracer, was used to assess the pathways of water and solute in the soil profile. The movement and fate of three commonly used herbicides: Trifluralin, Metolachlor, and Metribuzin were determined. The data gathered from the herbicide study were used to compare with the results of simulation to validate the pesticide component of the GLEAMS model.

The study was conducted at the Ben Hur Research Farm of the Louisiana Agricultural Experiment Station. Five relatively flat plots (< 0.2% slope) were used in the study; three of the plots were fitted with subsurface drainage system and two were surface drained. Climatic data were measured and recorded at the agriclimatic station adjacent to the experimental plots. Data recording was automated and files are maintained by the Louisiana AgriClimatic Information System of the LSU Agricultural Center.

Bromide concentrations were determined with an ion chromatograph from samples collected from two monitoring tubes installed at 1 m and 2 m depths in each plot . The average Br concentrations were significantly higher in the 1 m than in the 2 m depth in both drained and nondrained plots indicating that agricultural chemicals do not migrate deep into the aquifer but

stay near the surface of the water table. Soils with a shallow water table are probably more vulnerable to contamination than soils with a deep water table. Higher Br concentrations at 2 m depth were observed in the drained plots suggesting a possibility of a higher pollution potential risks in areas with subsurface drainage.

Results of herbicide study showed the direct relationship of surface runoff occurrence with time of herbicide application. The highest concentrations were contained in the first surface runoff after the application. Herbicide loss depends on runoff volume which is a function of precipitation among other variables. Estimated half-life of Trifluralin in soil was 46 days, Metolachlor, 27 days, and Metribuzin, 16 days.

GLEAMS simulation results showed underprediction of runoff loss for Metolachlor and Metribuzin while Trifluralin runoff loss was overpredicted by the model.

CHAPTER 1

INTRODUCTION

1.1. Statement of the problem

The heavy usage of agricultural chemicals such as fertilizers and pesticides has become a typical practice not only here in the U. S., but also worldwide. The importance of chemicals to modern agriculture cannot be overemphasized. They are responsible for maintaing the production in many areas. Drastic reduction of pesticide usage would lower the quality of agricultural products and increase production cost. Most fruit and vegetable crops would be more expensive, less available, and of lower quality without pesticides. According to one projection, there would be a 15 to 25 percent reduction in yield of grain crops by farmers in a mixed grain-livestock system if they stopped using nitrogenous fertilizers and pesticides (Smith et al., 1990). It has been estimated that for each percent decrease in crop production prices of agricultural products would increase by one to five percent depending on the crop (PPI & FAR, 1991).

With the worldwide increase in the need for food and fiber due to increasing population, the use of fertilizers and pesticides is expected to increase. While the use of chemicals is indispensable in modern agriculture, the chemicals may be intensifying pollution in streams and lakes. Sediments and chemicals transported by runoff from agricultural watersheds have been implicated as a major non-point sources of pollution (Stewart et al., 1975). Because of yearly application, the chemicals may be carried by the infiltrating water downward to the water table where they can migrate in the groundwater flow regime. And once a contaminant enters a groundwater source, the inherent transport mechanism of the aquifer will move the contaminant throughout the aquifer.

Areas with shallow water table may be more susceptible to pollution than an area with deep water table. Percolating water from precipitation may dissolve chemicals present in the soil profile and conduct the contaminants easily to the shallow water table. Schmidt and Sherman (1987) indicated that the most vulnerable to contamination by agricultural chemicals appears to be formations of sandy soils and shallow groundwater. Shallow water tables are often caused by excessive precipitation. A portion of this excess water infiltrates into the soil and causes the water table to rise near the surface for an extended periods of time. Another probable cause of shallow water table is the presence of impermeable hard pan or clayey layer in the lower soil horizon. This layer serves as a physical barrier to the downward flow of the percolating water. The condition of shallow water table enhances high percentage of rainfall to become surface runoff carrying chemical contaminants with it.

Fertilizers are categorized with respect to their content of nitrogen (N), phosphorus (P), and potassium (K) which are the main nutrients needed by crops. Of the three main nutrients, N in the form of nitrates is the one that most commonly cause contamination beneath agricultural lands. Pesticides, on the other hand, are classified by their biological usefulness, for example, insecticides, fungicides, algicides, and herbicides. But they are best classified according to their chemical properties which govern their behavior and persistence when introduced into the soil system. Various studies have cited groundwater contamination by pesticides and N fertilizers in over 800 of the 1,437 counties of the United States (NRC, 1989; Hall et al., 1989; Kanwar et al., 1988).

There are now hundreds of different chemical formulations available for application to agricultural watersheds, each having its own chemical and physical reactions. A report cited that over 1,000,000,000 kilos of more than 400 different types of pesticides are sprayed each year on America's cropland (NRC, 1989). The movement of agricultural chemicals in agricultural soils is complicated by the nature of the soil environment, which, according to Donigian and Rao (1986), is a dynamic, interdependent system of abiotic and biotic factors linked by physical, chemical, and biological processes. These processes influence the movement of chemicals introduced into the soil system.

The nationwide concern on environmental pollution had caused the passage of the "Clean Waters Act of 1972" which required the states to identify nonpoint sources of pollution and develop plans for control of such sources (USEPA, 1972). Its passage had stimulated many concerned scientists to develop computer models to evaluate nonpoint source pollution from diffuse agricultural areas. The move contributed to significant advances in model development. The complexity of nonpoint source of pollution coupled by the site specificity of a model will require additional information to properly monitor the movement of agricultural chemical contaminants.

In order to adequately describe the movement of agricultural chemicals, detailed data on the structure and properties of the soil, the groundwater system, and the flow of water on these systems are needed. Although these can be studied in the laboratory, field trials will provide data for verification and supplementation because field conditions are simply different from the controlled laboratory conditions.

1.2. Objectives of the study

The reported contamination of ground and surface water systems implicates the use of agricultural chemicals as the major nonpoint sources of pollution. Potential chemical loading is determined by the soil, the nature of the chemical, agricultural management practices, and climatic factors and their interactions. This study aims to determine the movement of selected agricultural chemicals in alluvial clayey soils with a shallow water table. Clayey soils with shallow water tables are common to Louisiana and the Lower Mississippi Valley (LMV) where large amounts of fertilizers and pesticides with relatively low crop-use efficiencies are used. The high precipitation coupled by the low-lying, nearly level topography of LMV makes the area susceptible to shallow water table formation. Shallow water tables, in many areas of the LMV, adversely affect agricultural crop production. The excess water in the root zone displaces oxygen and hinders the growth and development of plant roots. In many instances, shallow water table delays the planting of crops and consequently reduces the potential yield. The drainage of excess surface and subsurface water from croplands had been achieved with subsurface drainage system that utilizes drainage tiles or plastic tubing. The use of computer models to simulate agricultural chemical movement, in order to predict the contaminant loading, has gained acceptance. The validity of prediction, however, is subject to the validation of the model. Validation and testing were noted to limit model development and utilization.

Specifically, the objectives of the study are:

1. To determine the movement of Bromide ions through soils with and without subsurface drainage;

2. To determine the movement and fate of trifluralin, metolachlor, and metribuzin in fields with and without subsurface drainage;

3. To test and validate the accuracy of the Pesticide Component of the GLEAMS model (Leonard et al. 1987) in estimating chemical transport in soils with a shallow water table.

CHAPTER 2

REVIEW OF LITERATURE AND RELATED STUDIES

Agricultural chemicals are an essential part of the crop management program of today's modern farming. The objective of any application of agricultural chemicals is sustained profitable production. Agricultural chemicals, however, pose a considerable threat to the environment because they become pollutants when they are transported away from the intended targets. The major challenge is to devise management programs that reduce the potential for pollution while achieving optimum yields and returns for farmers. This may be accomplished if the factors and processes involved in the movement of agricultural chemicals and other related information relevant to their behavior in the soil-water-plant systems are better understood.

2.1. Factors affecting pollution potential

The U. S. Environmental Protection Agency (EPA) reported that at least 46 pesticides have been detected in groundwater in 26 states as a result of normal agricultural use (U. S. EPA, 1988). The contamination of the groundwater can be attributed to several factors such as soils, climate, agricultural chemical properties, farm management practices, and time. The degree of pollution potential of agricultural lands depends on these factors and their combinations because they influence the fate and movement of agricultural chemicals within the soil. The relative effect of each of these factors, however, varies from place to place.

2.1.A. Essential soil properties

The soil properties of interest in assessing the pollution potential are those characteristics that facilitate contaminant entry into and movement within the soil profile. These properties are determined by the nature of the soil as influenced by the soil forming factors such as the parent material, climate, biotic activity, topography, time, and the manner by which the soil was formed. The resulting soils vary from one location to another and each exhibit differences in properties.

2.1.A.1. Soil texture and soil structure

Soil texture and soil structure are two important physical properties of the soil in that they influence most other soil characteristics such as porosity, bulk density, water holding capacity, and hydraulic conductivity. Soil texture refers to the relative proportion of the particles of various sizes while soil structure is the arrangement of the soil particles into groups or aggregates. These soil properties help determine the water and nutrient supplying capacity of the soil.

The percentage composition of the amount of coarse and fine particles determines the textural class of a soil. Figure 1 shows the USDA soil textural triangle used to determine the textural class of a soil. Soil types are named according to their texture such as clay loam or silt loam. The broad classes of

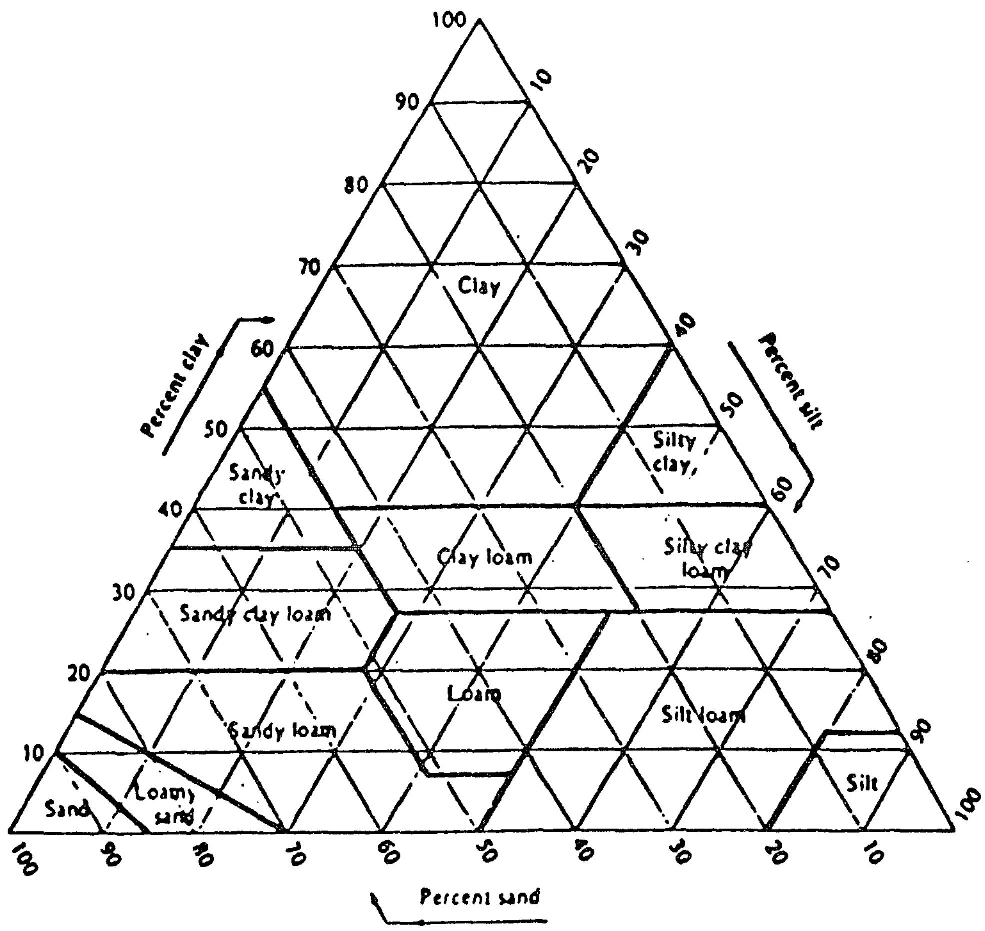


Figure 1. Soil textural triangle used to determine the soil textural class (from USDA, 1962).

texture range between sand at one extreme and clay at the other. Table 1 presents the size limits of soil separates in the U. S. Department of Agriculture (USDA) and in the International Systems. Two basic types of clay minerals are present in most soils. They are the expanding types such as the smectite and vermiculite and the non-expanding types such as the kaolinite and illite. The expanding clays have much higher specific surface area and cation exchange capacities than non-expanding types. The surface area of the

Table 1. Size limits of soil separates (from Euroconsult, 1989).

USDA System		International System	
Name of separate	Equivalent diameter range (µm)	Name of separate	Equivalent diameter range (µm)
very coarse Sand	2.000 - 1.000		
coarse Sand	1.000 - 500	I. coarse Sand	2.000 - 210
medium Sand	500 - 250		
fine Sand	250 - 100	II. fine Sand	200 -20
very fine Sand	100 - 50		
Silt	50 - 2	III. Silt	20 - 2
Clay	below 2	IV. Clay	below 2

clay minerals is highly dependent on the extent of the expansion of clay lattices. The absorption of water, hence nutrients and chemicals, and the attraction of particles with one another are function of surface phenomena thus the significance of high specific surface area is obvious. Water and contaminant transport is more rapid in coarse textured soils than in fine textured soil. For example, sandy soils have coarser texture and do have large spaces between particles; the passage of air and water is rapid. In contrast, clayey and silty soils have finer textures and their water holding capacities are high. The partition of rainfall between surface runoff and infiltration is biased towards the latter in sandy soils. When a soil in the field dries, it may reach a very low water content at the surface but a soil containing sufficient clay to significantly affect chemical properties is seldom dehydrated under relative humidities prevailing in nature.

Organic matter present in the soil consist of two groups: undecayed plants and animal tissues and those that are more or less completely decomposed or resynthesized products. The latter group are commonly called humus. The former are transient materials serving as substrate for the production of humus. Soil humus comprise approximately 85 to 90 percent of the total organic matter in soils (Weber and Weed, 1974). The active portion of soil humus is made up of various humic acids, fulvic acids, and free radicals. The humic acids are believed to be responsible for the cation- and anion-exchange properties exhibited by soil organic matter. The soil organic matter is usually regarded to be a primary absorber of nonpolar organic compounds (Leonard and Knisel, 1988; Leonard et al., 1988).

The texture class found in a soil contributes to its structure. Soil structure is dependent upon the amount of clay and organic matter present. Soils that are a mixture of clay, organic colloids, and larger particles develop an aggregated structure that are best fit in agriculture. Soils deficient in clay or organic colloids are structureless while soils too rich in clay and lacking in larger particles may form heavy pans almost impenetrable to water or plant roots. Soils with poorly developed structure readily wash away through the action of water, but well aggregated soils are erosion resistant because they can readily absorb water and eliminate much surface runoff. Figure 2 shows the volume distribution of organic matter, sand, silt, clay, and pores of macro and micro sizes in a representative sandy loam (a) and silt loam (b) soils.

2.1.A.2. Soil reaction

The term soil reaction is used to denote the degree of "acidity" or "alkalinity" of a moist soil. This is indicated by the hydrogen-ion concentration in the soil solution. Soil reaction is measured and presented as the pH value which equals the negative logarithm of the H-ion concentration. The higher the H-ion concentration, the lower its negative logarithm or pH value and the more acid the soil reaction. Figure 3 shows the pH ranges of most mineral soils and the ranges commonly found in humid regions. The primary influence of soil reaction is the functioning of plant roots. The beneficial soil micro-organisms as well as pathological soil-borne organisms are also affected by the soil reaction. Most plants and micro-organisms thrive best in soils of a pH = 6 to 7.5 although plant species and even varieties may differ in the degree to which they favor or tolerate pH beyond that range.

The availability and solubility of various plant nutritive elements and certain chemical compounds are influenced by the soil reaction. The cation exchange capacity (CEC) and anion exchange capacity (AEC), which are responsible for the retention of chemicals in the soil, are affected by the pH. Many organics form negative ions at high pH, positive ions at low pH and neutral species in the intermediate pH ranges. Extreme pH values may result in toxic concentration of certain chemicals, i.e., extreme acidity will cause Al

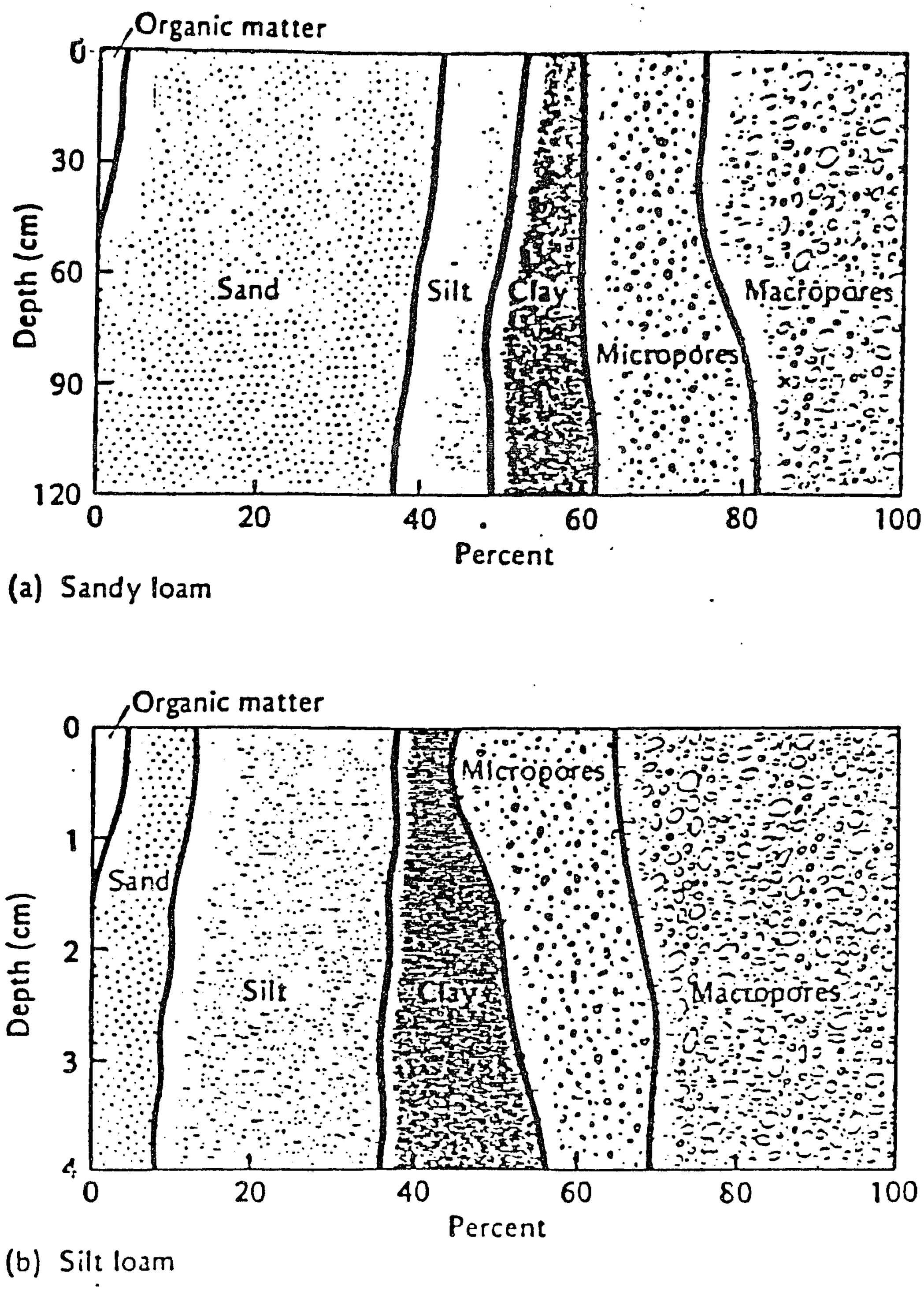


Figure 2. Volume distribution of organic matter, sand, silt, clay and pores in a representative sandy loam (a) and silt loam (b) soils (abridged from Brady, 1984).

and Mn toxicity while high pH renders ammoniacal fertilizers to produce NH_3 gas especially toxic to germinating seeds. In addition, pH affects the charge on the surface altering its ability to absorb materials and with many different materials with different adsorption properties, competition in some way results. Generally, adsorption is increased at pH ranges where the species is neutral in charge.

2.1.A.3. Soil moisture content

Soils hold water in two ways: as capillary moisture in pores that occur between solid particles and as adhesive or swelling moisture by adsorption on the solid surfaces of clay mineral and organic particles. The former type of

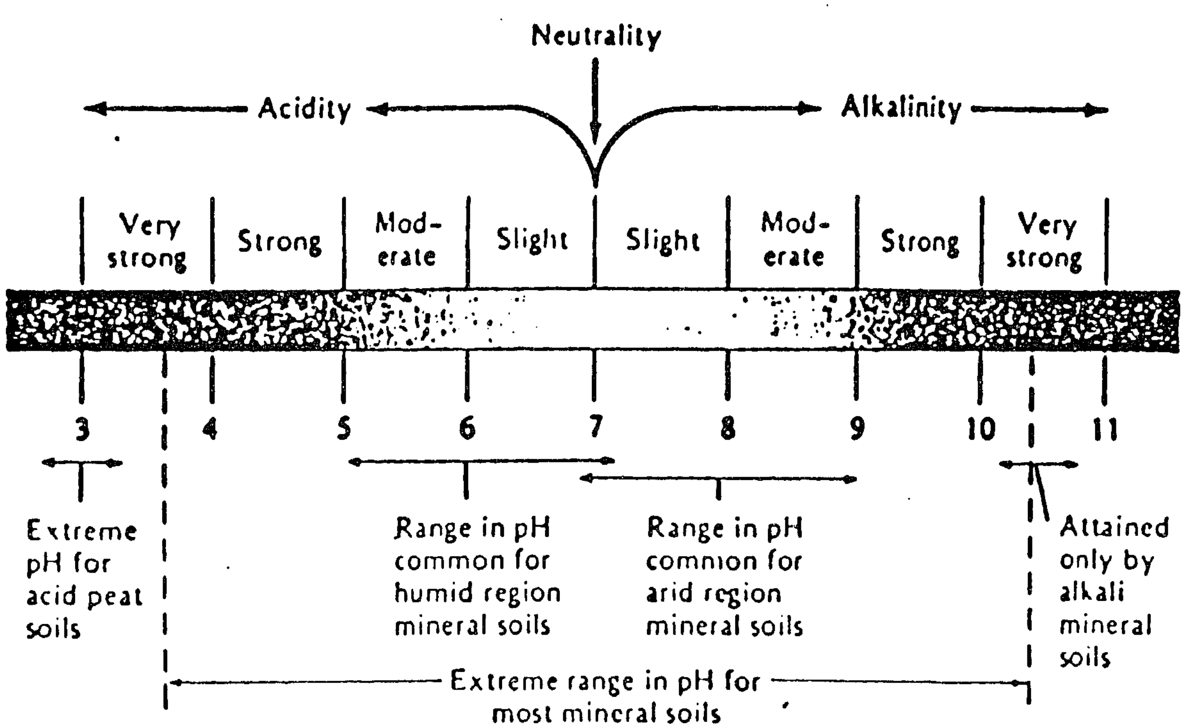


Figure 3. Extreme range in pH for most mineral soils and the ranges commonly found in humid regions (from Brady, 1984).

soil moisture is the available type and will be the focus of the discussion. This available moisture content of soil serves as the source to satisfy the evapotranspiration of growing crops. Soil water is the primary solvent in making up of the soil solution (Brady, 1984) which is the main source of nutrition of plants. The moisture content of the soil is determined by the water holding capacity of the soil. The soil moisture content influences the amount of surface runoff during rain and consequently the incidence of soil erosion. According to Truman and Bradford (1990) antecedent soil water content is an important variable affecting soil erosion processes and may be responsible for much of the variation in splash and wash erosion rates. In their study, they found that antecedent soil moisture conditions prior to rainfall influenced the amount of splash detachment and the physical processes that control the amount of splash. Their theory was reinforced by Alberts (1991) through a laboratory rainfall simulation. He showed that initial water content affects the interrill soil erodibility parameter. A linear relationship between the interrill soil erodibility parameter and initial soil water content explained 82 percent decrease in the variation of the interrill erodibility parameter. He observed a 35 percent decrease in the erodibility parameter as the initial water content was increased from air dryness to 20 percent. Wischmeier and Mannering (1969) found antecedent soil moisture to be a significant term in their multiple regression model for soil erodibility.

Soil moisture content influences the distribution and movement of nutrients and chemicals in the soil profile. Water moves downward in quantity during and immediately after rain or irrigation. The amount of surface runoff usually is the excess water over the amount that infiltrates into the soil from precipitation. The principal movement of water occurs as a liquid in capillary films or through capillary pores but some movement also occur in the vapor form. The average rate at which infiltrated water moves through the soil profile can be calculated if the field capacity of the soil and the recharge rate from precipitation, irrigation, or any other source are known. Figure 4 illustrates the soil-plant-atmosphere continuum where the water movement can be traced as it is added to soils through precipitation and irrigation, as it behaves in soils, is lost directly to the atmosphere or is absorbed by plants, transported upward and subsequently evaporated into the atmosphere.

The soil water velocity is the total recharge rate divided by the subsurface volume through which water can move, that is, the water content of the soil. Water content varies in time and in general it is recognized that data on soil availability are difficult to obtain in the field. A nomograph such as that illustrated in Figure 5 constitutes a useful guideline in the estimation of soil water availability in the absence of a more detailed "observed" information. The figure presents the water availability threshold for various soil types. A practical upper limit to the water content is the field capacity moisture content which can be estimated for a given soil.

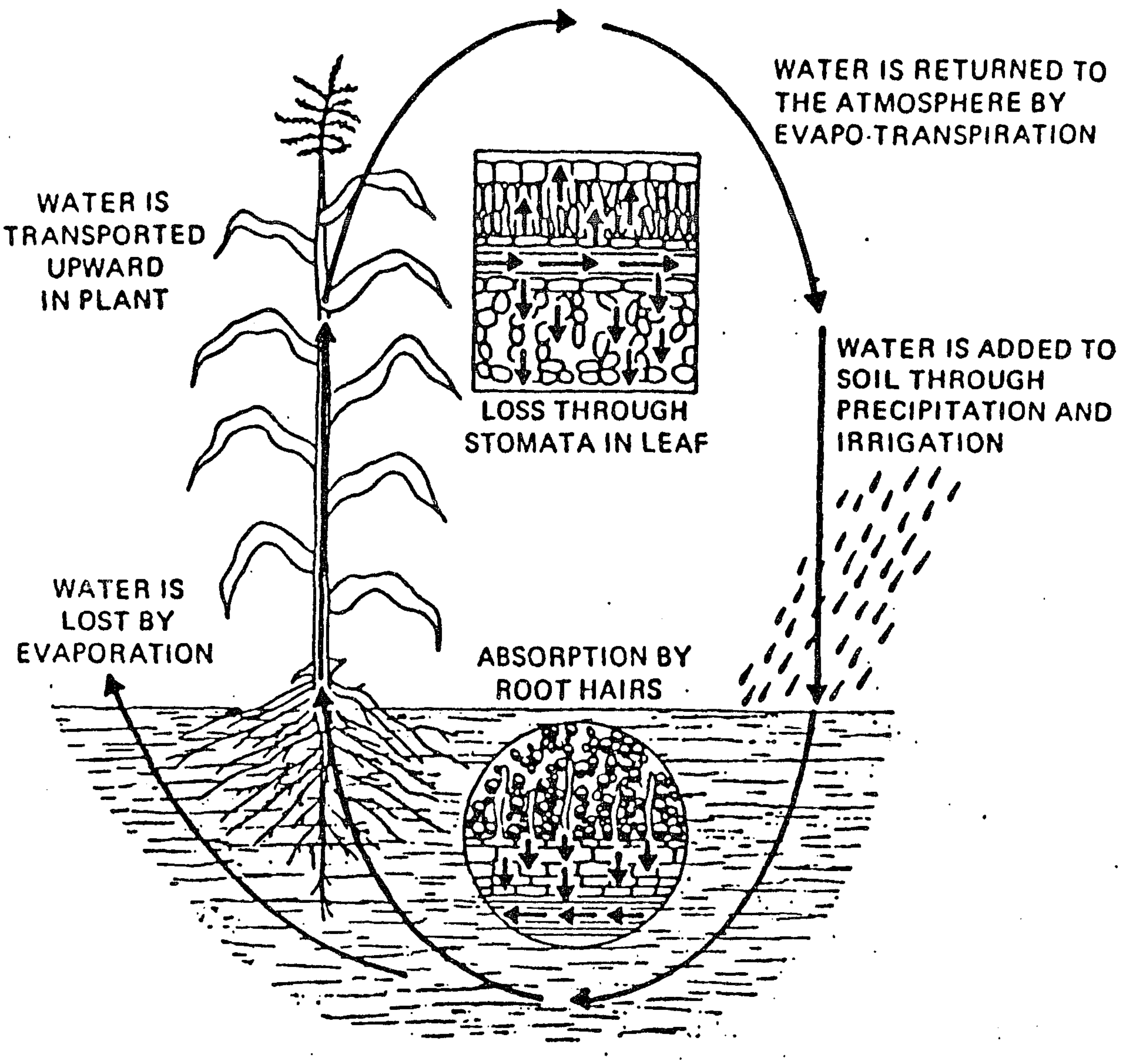


Figure 4. The soil-plant-atmosphere continuum which illustrates the movement of water from the atmosphere, through the soil and plant and back to the atmosphere (from Brady 1984).

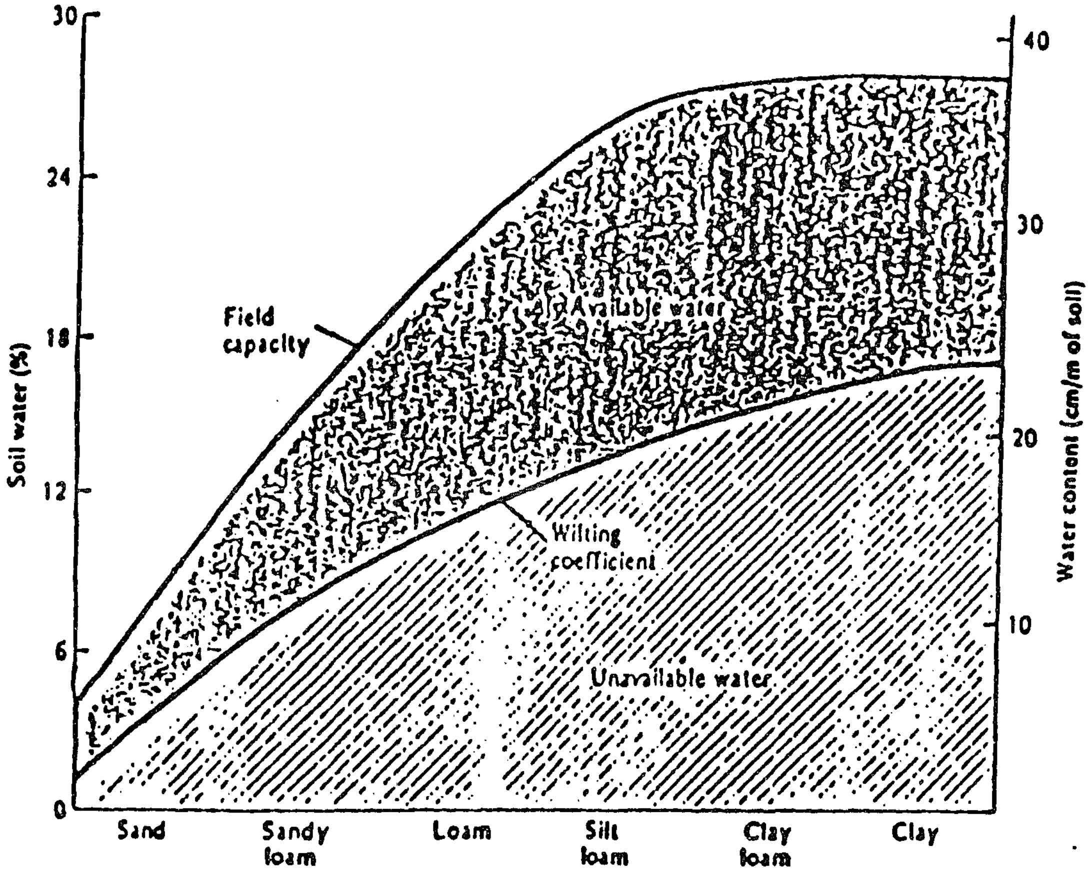


Figure 5. Water availability threshold for various soil types (from Brady, 1984).

2.1.A.4. Soil air

Following a rain or irrigation, soil water starts to vacate the pore spaces as water is removed by evapotranspiration and percolation. Air simply moves into those spaces not occupied by water. Soil air, as with the atmosphere, is made up of several gases such as nitrogen, oxygen, and carbon dioxide in remarkably constant proportions. The respiration of organisms and the decomposition of organic residues by microorganisms render the proportion of these gases to be imbalanced. But unlike the atmosphere where air movement and diffusion easily eliminate gaseous differences quickly, the composition of the soil air adjusts slowly. As a result, the soil atmosphere always contains less O_2 and more CO_2. Under this condition, several soil organisms may carry on anaerobic respiration for a time but such activity will result in chemical changes which may affect other processes such as inhibition of root growth, death of some organisms, decreased decomposition of organic residues and reduced absorption. Soil air has the most relevance to the population and growth of micro-organisms in the soil which in turn affects the speed of microbial degradation processes .

2.1.A.5. Soil organism

Vast numbers of organisms, both micro and macro, live in the soil and are responsible for the degradation and synthesis of organic materials and residues to humus. Organisms (plants and animals) are classified into groups such as primary, secondary, and tertiary consumers because of the difficulty to study them independently (Brady, 1984). Organisms that prey on dead and decaying plant tissues, such as mites, snails, beetles, centipedes, and earthworms and microflora (bacteria, fungi, algae, lichens), are termed primary consumers. Secondary consumers are organisms that feed on the primary consumers and moving up the food chain are the tertiary consumers which feed on both primary and secondary consumers and other organic materials. Table 2 lists examples of microphytic feeders and of carnivores that act as secondary and tertiary consumers within or on top of soil.

Table 2. Examples of microphytic feeders and of carnivores that act as secondary and tertiary consumers within or on top of soil (from Brady, 1984).

Microphytic feeders		Carnivores			
		Secondary consumers		Tertiary consumers	
Organism	Microflora consumed	Predator	Prey	Predator	Prey
					Spider
	Algae		Collembola		Centipedes
Springtails	Bacteria	Mites	Nematodes	Ants	Mites
	Fungi		Enchytraeids		Scorpions
	Fungi				
Mites	Algae		Collembola		Spiders
	Lichens		Nematodes	Centipedes	Mites
		Centipedes	Snails		Centipedes
	Bacteria		Slugs		(other)
Protozoa	and other		Aphids		
	microflora		Flies		
					Spiders
		Mole	Earthworm	Beetles	Mites
			Insects		Beetles
					(other)
Nematodes	Bacteria				
	Fungi				
Termites	Fungi				

Hutchins (1984) conducted a series of soil column tests and experiments to evaluate microbial removal of trace organic compounds during rapid infiltration recharge of the ground water. Most of the removal occurred in the upper meter of the soil indicating higher microbial activity in the upper soil layers. However, microbial adaptation was found evident for some compounds while other compounds appeared to exhibit a minimum concentration below which biodegradation did not proceed.

2.1.B. Climatic factors

Climate plays a significant role in the movement of agricultural chemicals. Climatic factors reported to affect the rate of chemical movement include precipitation, temperature, relative humidity, wind, and solar radiation.

2.1.B.1. Precipitation

Precipitation, in the form of rain, is the main source of water exclusive of irrigation. Most researchers report that rain has the most dramatic effect on pesticide residues on plants and soil of all the climatic factors. Linscott and Hagin (1968) and Linskens et al. (1965) found the extent of residue removal to be related to rainfall amount and intensity but Willis et al. (1982, 1986) found rainfall amount to have considerably more influence than rainfall intensity. Most studies indicate that pesticide removal is greatest if rainfall occurs within 24 hours after pesticide application. White et al. (1967) reported that a 6.3 cm rain within one hour after application of 3.36 kg per ha of atrazine resulted in the loss of 17 percent of the applied herbicide in runoff. If the rain was delayed 96 hours, they showed that only 7% of the applied pesticide would be lost. Leonard et al. (1979) showed that 1 percent of the seasonal cyanazine loss from corn occurred in the first runoff.

2.1.B.2. Temperature, wind, and humidity

Although temperature, wind, and humidity are not included in most transport equations in the literature, they affect pesticide movement through their influence on pesticide vapor pressure and volatility. Temperature, wind, and humidity were related to volatile losses of toxaphene and DDT from cotton plants in field studies which indicated that volatility was a major pathway for these insecticides (Willis et al., 1980a; Harper et al., 1983). High temperature and low humidity increase the evaporation rate of water thus influencing evapotranspiration and water and chemical movement in the soil system. The rate of water loss from the soil or from the plant leaves is determined basically by differences in moisture potential identified as the vapor pressure gradient which is the difference in the vapor pressure at the leaf or soil surface and that of the atmosphere. Low soil temperatures are known to increase the persistence of many herbicides in soils (Hormann et al., (1979). Temperature was also known to affect survival of microorganisms in the soil. Soil temperatures are generally lower in the subsoil. Consequently, the micro-organism population and the organic matter content are also lower in the subsoil.

2.1.B.3. Solar radiation

The evapotranspiration rate over an area is significantly influenced by solar radiation. A review of evapotranspiration formulae show solar radiation as a direct function in the calculations (Ritchie, 1972; Jensen, 1966; Penman, 1948 and 1963). Evapotranspiration is known to affect the movement of water both in the surface soil and in the root zone, hence, it influences the movement of agicultural chemicals. Pesticide persistence is also affected by solar radiation through photochemical alteration of the pesticide. Photochemical alteration is caused by the ultraviolet portion of the sunlight primarily in the 300 to 400 nm wavelenght range. The photochemical alteration products may either be more or less toxic than the original pesticide.

2.1.C. Agricultural chemical formulation and properties

Laboratory and field tests on the many different kinds and types of agricultural chemicals show great variability in behavior in soils and aquifers (Lyman et al., 1982; Hartley and Graham-Bryce, 1980). The differences in chemical behavior are brought about by the chemical formulation and by the inherent nature of the agricultural chemical.

2.1.C.1. Chemical formulation

The formulation of agricultural chemicals contribute to the different properties relevant to chemical movement and to possible pollution of the receiving soil system. Not all forms of agricultural chemicals show similarity in behavior. For example, acid and salt form of some herbicides have low volatility but with high solubility while the ester forms are just the opposite (Frere, 1973). The differences in water solubility and volatility have profound effect on the mobility of chemicals in the soil.

Pesticides are manufactured in various physical forms: solids such as wettable powder, granules, dusts; liquids such as water solubles, oil solubles or emulsified concentrates; gels such as fumigants; and gases (fumigants). Various additives (wetting agents, emusifiers, detergents, spreaders, sticking agents, and dispersing agents) are added to pesticide mixtures to improve handling and storage characteristics and effectiveness. Pesticides formulated as emulsifiable concentrates are generally considered to be more resistant to weathering than those formulated as dust or wettable powders (Wauchope, 1978; Ebeling, 1963).

2.1.C.2. Chemical properties

The nature of each chemical is a composite function of its molecular structure. It is expressed by the chemicals' ionizability, solubility, and volatility. Chemicals which ionize in aqueous solutions to yield positively charged ions behave differently than those that yield negatively charged species in soil systems. Cationic, basic, and anionic chemicals, in turn, behave differently than uncharged or non-ionic pesticides. Listed in Table 3 are selected pesticides and some properties relevant to its reactions. Cationic

Table 3. Selected pesticides and some properties relevant to its reaction (from Weber and White, 1974).

Class	Chemical type	Common Name	Water Solubility	pK_a
Cationic	Bipyridilium quartenary salts	Diquat	very slight	
		Paraquat		
Basic	s-triazines	Atrazin	35	1.68
	s-triazine	Propazine	4.8	1.85
	s-triazines	Simazine	5.0	1.65
	s-triazines	Prometryne	40	4.05
	s-triazines	Prometone	677	4.28
	s-triazole	Amitrole	2.8×10^5	4.17
Acidic	Phenoxy Acid	2,4-D	650	2.80
	Benzoic Acid	Dicamba	4500	1.93
	Picolinic Acid	Picloram	430	1.90
	Phenol	Dinoseb	52	4.40
	Benzoic Acid	Amiben	700	3.40
Nonionic	Chlorinated hydrocarbons	DDT	0.001-0.04	
		Endrin	0.1 - 0.23	
		Dieldrin	0.1 - 0.25	
		Aldrin	0.01- 0.2	
		Toxaphene	0.4	
		Lindane	7.3 - 10.0	
		Chlordane	very low	
		Heptachlor	very low	
Nonionic	Organophosphates	Parathion	24	
		Diazinon	40	
Nonionic	Dinitroanilides	Nitralin	0.6	
		Benefin	0.5	
		Trifluralin	0.05	
Nonionic	Phynylcarbailates	Propham (IPC)	250	
		Chlorpropham	88-102	
		Carbaryl	40-99	
Nonionic	Phenylurias	Fenuron	2900-3850	
		Monuron	230	
		Diuron	42	
		Floumeturon	90	
		Linuron	75	
		Metabromuron	330	
		Propachlor	700	
		Propanil	500	
Nonionic	Substituted	Diphenamide	260	
	Anilides	EPTC	370-375	
Nonionic	Thiocarbamates	CDEC	92	

species are readily adsorbed by soil colloids while species of anionic properties are adsorbed in smaller amounts (Weber and Weed, 1974).

Solubility refers to the tendency of a chemical to move from solid into solution and is usually expressed as the concentration of a saturated solution in equilibrium with excess solid. This equilibrium process is dependent on the balance between those forces holding the molecules or ions in the solid and the solvating ability of the particular solvent. The solubility of a chemical is measured and expressed as an equilibrium constant usually referred to as the partition coefficient, or on some occasions, a distribution ratio. A commonly used partition coefficient is the octanol-water partition coefficient (K_{ow}). The K_{ow} describes the partitioning of a pesticide between a polar phase (water) and a relatively non-polar phase (1-octanol). The octanol-water partitioning is likened to the partitioning (adsorption) in an aquifer of a pesticide between water and the organic matter content. Table 4 shows a partial listing of Log K_{ow} values for some selected pesticides by Rao and Davidson (1980).

Chemicals with low water solubility are known as hydrophobic, i.e. DDT (water solubility of 1 ppb) and other chemicals are hydrophilic such as paraquat (70% water soluble). The solubility property is important in determining the bonding mechanism and hence the mobility and bioactivity of the chemical. Comparison of relative solubilities, however, must be limited to chemicals with similar properties. Highly soluble chemicals are generally more mobile. An additional factor which can affect solubility of pesticides is

Table 4. Log K_{ow} values for some selected pesticides (from Rao and Davidson, 1980).

Pesticide	Log K_{ow}
(a) Herbicide	
Alachlor	2.64
Atrazine	2.33
Diuron	2.81
Simazine	1.94
2, 4-D	2.64
2, 4, 5-T	0.85
(b) Insecticide	
Aldicarb	0.70
Chlordane	3.32
DDT	5.57
Dieldrin	3.69
Lindane	2.81

the presence of electrolytes in the soil solution. Freed (1966) found that the solubilities of three carbamate herbicides in soil solution were about half the solubilities as measured in distilled water.

The extent of chemical vaporization is dependent upon its vapor pressure, water solubility, adsorptive characteristics and formulation plus the soil temperature, air movement, and soil moisture content. The vapor pressure of a chemical is an indication of the relative ease by which the compound changes from the solid or liquid state into the vapor state. Table

5 presents the vapor pressure of some selected pesticides at the measured temperature. Non-volatile compounds such as DDT have low vapor pressure which will increase their persistence on and in the soil. Pesticides with high vapor pressure easily volatilize from the soil surface and have not been considered a threat to pollution. The volatility of a chemical is greater in moist soil than in dry soil because water competes with the chemical for adsorption sites and may concentrate the chemical at the soil or water surface. The actual volatility of a chemical is critically changed in the presence of water. This aqueous volatility is determined by dividing a chemical's vapor pressure by its solubility and this value is termed Henry's Law Constant. High water solubility can cause high vapor pressure chemicals to remain in the soil when they are applied just prior to irrigation or rainfall.

2.1.D. Farm management practices

Several farm management practices were reported to have influence in the movement of agricultural chemicals and affect groundwater vulnerability to pollution. These are: rate, timing, and method of chemical application; irrigation and drainage practices; and tillage practices.

2.1.D.1. Rate, timing, and method of chemical application

The rate of application is generally a function of the application objective. It suggests how much and how often a chemical is applied to the soil to attain the objective. It is pertinent to chemical movement in that the greater the amount of chemicals applied will provide a greater amount of

Table 5. Vapor pressure of some selected pesticides at the measured temperature (from Guenzi and Beard, 1974).

Type of pesticide	Common Name	Vapor pressure (mm Hg)	Temperature (Celsius)
Acids	Picloram	6.2×10^{-7}	35
	Dicamba	3.8×10^{-3}	100
	2,4-D	4.0×10^{-1}	160
Clorinated	Heptachlor	3.0×10^{-4}	25
hydrocarbons	Lindane	1.3×10^{-4}	30
	Chlordane	1.0×10^{-5}	25
	Endrin	2.0×10^{-7}	25
	Dieldrin	9.9×10^{-6}	30
	P,p'-DDE	6.5×10^{-6}	30
	o,p'-DDT	5.5×10^{-6}	30
	p,p'-DDD	1.0×10^{-6}	30
	p,p'-DDT	7.3×10^{-7}	30
Dinitroaniline	Trifluralin	2.0×10^{-4}	29.5
Organo-	Parathion	9.1×10^{-5}	30
Phosphates	Malathion	4.0×10^{-5}	30
Phenylurias	Fenuron	1.6×10^{-4}	60
	Monorun	5.0×10^{-7}	25
	Diuron	3.1×10^{-6}	50
s-triazines	Prometone	7.9×10^{-6}	30
	Prometryne	4.0×10^{-6}	30
	Atrazine	1.4×10^{-6}	30
	Propazine	1.6×10^{-7}	30
	Simazine	3.6×10^{-8}	30
Thiocarbamates	EPTC	3.4×10^{-2}	25
	CDEC	2.2×10^{-3}	200

chemicals subject to transport. The persistence of agricultural chemicals beyond the critical period for control leads to residue problems. Ideally, chemicals such as pesticides should retain activity long enough to accomplish the critical control then decompose to innocuous products before it is necessary to apply again (Hiltbold,1974).

The timing of chemical application can be a major factor in determining pollution potential of agricultural lands depending on local environmental conditions, rainfall, and temperature. As discussed earlier, even highly volatile chemicals will increase their persistence if applied prior to irrigation or rainfall. Prudent timing of chemical application will be the best means of controlling contamination and chemical losses.

Chemicals are applied to crops by aerial spraying, surface soil application (granular, dust, or liquid formulations), soil injection, soil incorporation, or through irrigation. Each of these methods of application may create the hazards of contaminating nontarget areas or damage nontarget organisms. Soil injection and soil incorporation are generally considered to pose the greatest likelihood for groundwater contamination.

2.1.D.2. Irrigation and drainage

Irrigation is the application of water to a field to supplement moisture content and support evapotranspiration requirements. It increases the soil moisture and flow through the soil, raising the potential for chemical leaching. Excess irrigation may also carry pesticides down well casings of abandoned or poorly constructed wells and directly inject contaminants to an aquifer. On the other hand, irrigation can decrease the amount of volatilization of some pesticides from the soil.

A new method of chemical application was reported by Comis (1990) dubbed as chemigation. It is a method of applying agricultural chemicals through the irrigation water. A measured quantity of the chemical is released at a controlled rate into the irrigation water by equipment designed for the purpose. According to him, the simulation of chemigation with 10 major herbicides and one nematicide on two soil types conducted by USDA-ARS at Tifton, Georgia using the GLEAMS model showed that the average chemical losses favored chemigation although there were years in the simulation when leaching was higher with chemigation. Everts and Kanwar (1990) used chemigation in their study to estimate the preferential flow to a subsurface drain by applying the tracers through sprinkler irrigation.

In areas with shallow water table like those in the Lower Mississippi Valley, subsurface drainage are often employed to remove excessive soil moisture. Reports from previous studies suggest that subsurface drainage does not only reduce the quantity of surface runoff but also improves its quality (Southwick et al., 1990; Bengtson et al., 1988; Baker and Johnson, 1976). According to Southwick et al. (1990) the reduction in surface runoff was due to the increase in the soil infiltration rate brought about by the reduction of soil moisture content by the subsurface drains. Bengtson et al.

(1989) investigated the influence of subsurface drainage on herbicide losses in southern Louisiana. They reported that subsurface drainage reduced atrazine and metolachlor losses by 55 and by 51 percent, respectively.

2.1.D.3. Tillage practices

The methods of soil manipulation by which land is prepared prior to planting are termed tillage practices. Early tillage practices, also known as conventional tillage, include plowing, disking, and harrowing. The purpose of tillage practices are to control weeds, to present a suitable seed bed for crop plants, and to incorporate organic residues into the soil. The number of plow pass required to produce the desirable tilth depends on the crop requirements. Some crops need a thoroughly mixed, pulverized, and leveled soils while others require raised beds or ridges. Research showed that conventional tillage yields a loosely packed top layer which resulted to higher infiltration rates (Edwards et al., 1984). With high infiltration rate, the residence time and the contact area of the infiltrating water with the soil minerals and the organic matter is greatly enhanced, thus, greater amount of chemical adsorption can be expected.

In the recent adoption of a new tillage practices, dubbed as conservation tillage, the plowing and other earthmoving activities are minimized during land preparation. Conservation tillage had been shown to reduce pesticide concentration in surface runoff but it tends to develop macropores (Richards et al., 1988). The macropores, i.e. soil cracks, earthworm burrows, and root channels tend to be continuous from the surface down deep into the subsoil and was observed to penetrate to depths exceeding one meter (Ehlers, 1975). Due to the reduced plowing or even no-tillage, the original macropores are left intact and the infiltrating water is able to by-pass the upper layers to the subsoil. According to Lee (1985), earthworm channels are important chemical pathways because they may last 50 to 100 years, are more permanent than root channels, and they do not open and close during seasonal shrink/swell episodes like soil structural cracks do.

2.1.E. Time

Time is a generic term which refers to a period where it acts as an agent to effect an observable change. The change may be in appearance, composition, or any distinguishing characteristic of the entity. For example, the time interval between application of the chemical and the first rainfall sufficient to produce runoff has a significant effect on the quantity of chemical lost in the surface runoff. Normally, the potential for herbicide loss decreases rapidly with increasing time after application. The differences in the length of time agricultural chemicals have been exposed to degradation agents has a pronounced effect in the chemical and physical composition of the agricultural chemicals.

2.2. Processes affecting agricultural chemical movement

There are several processes which affect the movement of agricultural chemicals in the soil environment under field conditions. The processes affecting the movement and fate of pesticides in the soil environment are shown in Figure 6. These processes are sorption, leaching, degradation and transformation, volatilization, and plant uptake. The interaction of these processes over time and space determine the fate and movement of chemicals in soils.

2.2.A. Sorption and leaching

Even though the water content of the soil may be quite low, the thin film of water coupled to the soil materials will react with the applied chemical and form the soil solution. Simultaneously, the adsorption process, a component of sorption, begins where chemical molecules adhere to the soil

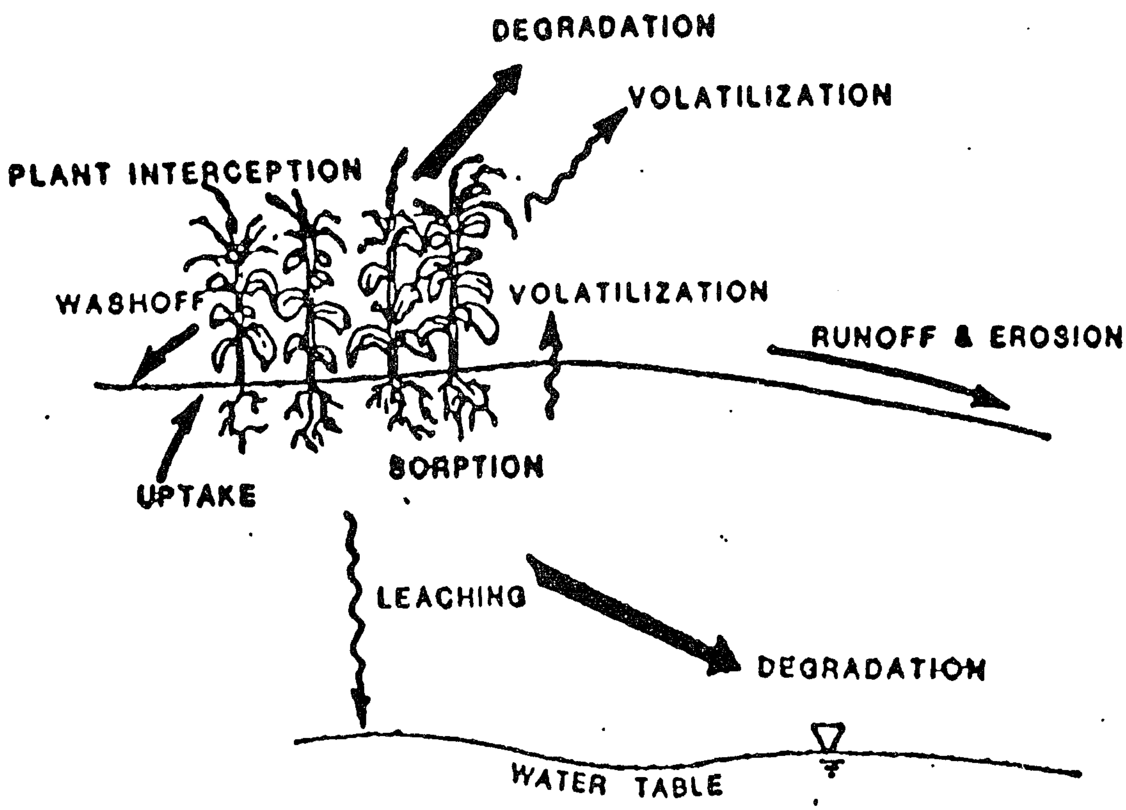


Figure 6. The processes that affect the movement and fate of pesticide in the soil environment (from Donigian and Rao, 1986).

particles. Adsorption has a critical influence on the mobility of the chemical because it decreases pesticide mobility in the vadose zone (soil surface to groundwater) (Donigian and Rao, 1986). The adsorption characteristics of chemicals range from highly adsorbed to no adsorption. Adsorption is determined to a large extent by the nature and properties of the chemical and the content of the soil material such as organic matter and clay minerals (Wagenet and Rao, 1985). Considerable studies have been done on adsorption of pesticides and other chemicals because of the large variety of chemical compounds and the differences between soils (Schwarzenbach and Westall, 1985; Rao and Davidson, 1980; Hamaker, 1975). As a first approximation on the amount of chemical adsorbed, the Freundlich equation (Freundlich, 1926) is usually used (Munster et al., 1991; Oddson et al., 1970). It is expressed as:

$$S=K*C^{n} \tag{1}$$

where:

S -- the amount of chemical adsorbed per unit weight of solid soil,
C -- the amount of chemical in solution per unit volume of water,
K -- adsorption coefficient, and
n -- slope of isotherm.

The use of the Freundlich equation assumes a linear, reversible equilibrium relationship between the quantity of solute in the sorbed and solution phases. Some researchers have found the assumption of linear equilibrium to be valid (Karickhoff et al., 1979) while others have observed the n-values in the range of 0.7 to 1.2 (Rao and Davidson, 1980; Hamaker and Thompson, 1972). They indicated however that even when non-linearity was evidenced, the isotherm is often observed to be linear at low concentrations. And when a linear isotherm is assumed, $n = 1$, the adsorption equation (1) becomes $S = K*C$, and the coefficient K is equivalent to the distribution coefficient (K_d) for ions (de Marsily, 1986). Pesticides with large K_d are strongly adsorbed whereas those pesticides with small K_d will residue primarily in soil solution provided the water solubility is not exceeded.

Whereas adsorption describes the retention of chemicals to the surface of soil particles, desorption defines the release of chemicals back into solution or vapor phase. Both adsorption and desorption processes occur simultaneously within the soil-water system where solute initially adsorbed at available surfaces desorbs into solution or vapor phase to maintain chemical equilibrium. According to Stover and Guitjen (1990) adsorption is generally reversible but desorption is not always complete. In most cases, chemical desorption is not described exactly by the same adsorption equation due to hysteresis. Figure 7 illustrates an example of hysteresis curve in the sorption process. Swanson and Dutt (1973) found that the desorption data could be described by the Freudlich relationship with $N_{ads}/N_{des} = 2.3$.

Leaching involves the vertical movement of a chemical from the point of application to a position deeper in the soil. Leaching occurs when chemicals are dissolved by the action of percolating water through the soil. The major factors that influence leaching are the chemical properties and the water recharge rate comprised of rainfall or irrigation minus evapotranspiration (Wyman et al., 1985). Two of the most important properties of pesticides that determine potential leaching below the plant root zone are affinity for adsorption by soil particle surfaces and pesticide persistence or half-life.

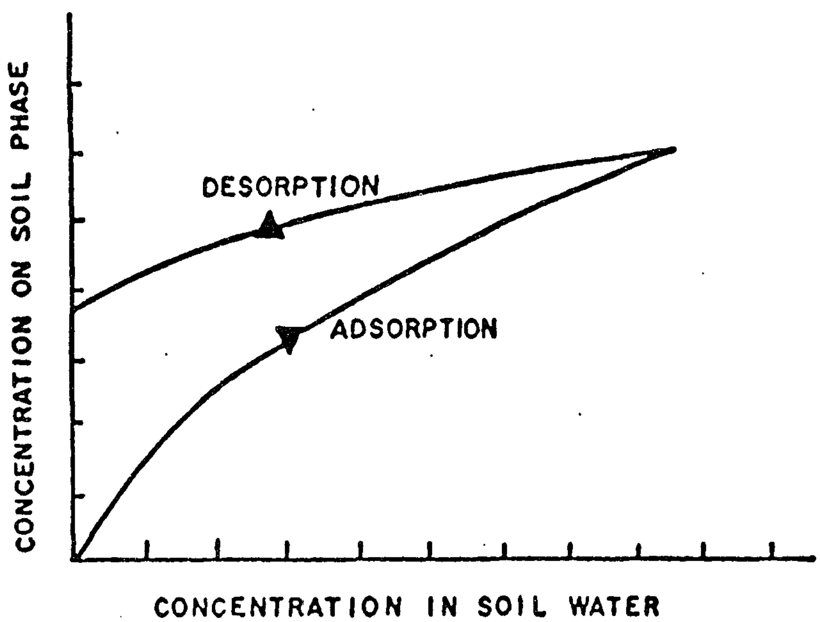


Figure 8. An example of hysteresis curve in the sorption process (from Stover and Guitjens, 1990).

Sorption will retard or attenuate pesticide movement relative to the movement of water. The basic premise for using retardation factors is that local equilibrium is a valid assumption (Goltz and Roberts, 1987). The leaching retardation factor can be written as:

$$R=1+\frac{K_{oc}*foc*\rho_b}{100*\Theta_{fc}} \tag{2}$$

where:

R = retardation factor,
K_{oc} = organic carbon adsorption coefficient,
foc = fraction of organic carbon in soil,
ρ_b = soil bulk density, and
Θ_{fc} = soil water content at field capacity.

The retardation factor indicates the velocity of water or a non-adsorbed chemical relative to the velocity of an adsorbed chemical. Thus a retardation factor of 2 would indicate that the adsorbed chemical would move at one half the velocity of a non-adsorbed species.

The distribution of pesticides in soil between solution and adsorbed phases under equilibrium conditions is defined as a constant and can be estimated by the simple relationship (Leonard et al., 1988):

$$K_{oc}=\frac{C_s}{C_w*foc} \tag{3}$$

where:

K_{oc} = adsorption coefficient based on soil carbon,
C_w = the chemical concentration in the soil solution,
C_s = the concentration adsorbed on a unit weight basis of soil,
foc = fraction of organic carbon in the soil.

The use of this relationship in predicting pesticides in runoff and leachate assumes rapid and reversible equilibrium which may be an oversimplification but within uncertainties in knowing the actual K_{oc} values, the relationship appears adequate for approximate or relative prediction (Rao et al., 1983). Leaching, when exceeding degradation rates, may result in residues reaching the groundwater.

2.2.B. Degradation and transformation

Degradation and transformation occurs in all locations where the chemical is: in the leaves of the plant, in the soil solution, or in the adsorbed phase. The rate of chemical breakdown may be considerably different at each location. Photodecomposition by sunlight and oxidation could occur easily on the susceptible chemical in the leaves of the plant or in the soil surface. In the soil solution, hydrolysis, and microbial decomposition have the greatest potential as mechanisms of degradation. On the adsorbed phase, reducing reaction may be catalyzed. Degradation below the root zone may be reduced due to low organic carbon content and lower microbial activity (Bouwer, 1987). The rates of all these reactions can be approximately described by a first order kinetic reaction (Jones, 1986; Knisel, 1980; Frere et al., 1975; Hermanson et al., 1971):

$$X_t = X_o \exp\left(-\frac{0.693t}{t_{1/2}}\right) \tag{4}$$

where:

X_t = the concentration at t days after application;
X_o = the initial pesticide concentration at day of application; and
$t_{1/2}$ = the half-life or half-concentration time, usually expressed in days, for degradation of one-half the pesticide.

According to Frere (1973) the rate coefficient can change slightly to as much as several folds for a 10 degree change in temperature in some chemical reactions. Reactions that depend upon microbes probably change two-fold for a 10 degree temperature change in the range of zero to 30 degrees Celsius (Stanford et al., 1972).

2.2.C. Volatilization

All solids and liquids tend to lose molecules to the gas form and this process is called volatilization. Volatilization is an important mode of dissipation when the chemical is on the soil or plant surface. Volatilization from the soil or from plant surfaces reduces the amount of chemical available for transport with runoff or to be leached with the percolating water. Volatilization also determines the quantity of chemicals which exists in the vapor phase available for diffusive vapor transport. Convection current near the soil surface will accelerate losses of chemicals by continuously removing the vapors from the air in contact with the evaporative surface.

Igue et al. (1972) found the loss of dieldrin from a soil at 20 percent water content and 100 percent relative humidity was 126 ng per sq cm in a 12-hour period as compared to 56 ng per sq cm from the same soil dried with air to less than 1 percent relative humidity. Their study showed that chemicals can be lost even with no net loss of water.

2.2.D. Plant Uptake

The uptake of available nutrients and chemicals by plants is determined by the supply of the nutrients and chemicals to the plant root surface and by the absorption rate at the root surface. The roots and root hairs penetrate the soil and in so doing come in direct contact with the soil colloids and the soil solution containing the chemicals. As the nutrients and chemicals are absorbed by the roots, a concentration gradient is developed between the area immediately surrounding the root and the soil zone farther from the root. In response to this gradient, ion diffusion toward the roots may take place.

The depth of soil exploited by the roots depends on crop species and age of the crop as well as the agricultural practices. It will be limited by the presence of hard pans and shallow water table. The form of the rooting system may also be limited where the crop grows and the availability of nutrients. For example, rice grown in Asia has generally a very shallow rooting system. Roots will tend to penetrate deeper in lighter soils particularly if rainfall conditions are not favorable. A schematic representation of two rooting systems is illustrated in Figure 9. Information on rooting depth is essential because it is where the water movement and pesticide problems occur.

The essence of systemic compound is uptake by roots and rapid translocation to other plant parts while foliar compounds rely on the absorption property and nature of the leaves. The tolerance of plants to herbicides is often due to their decomposition in the plant. However, not all pesticides are broken down and residues become a problem when a pesticide persists in a soil in quantities that can be adsorbed by untreated crops having no tolerance level for the pesticide. The contribution of plants in removing pesticide residues is generally masked by other modes of pesticide degradation.

2.3. Measuring agricultural chemical movement

Accurate prediction of the behavior of agricultural chemicals in the soil environment is hardly possible yet due to the complexity of field systems. Many factors and combinations of factors are responsible for the chemical

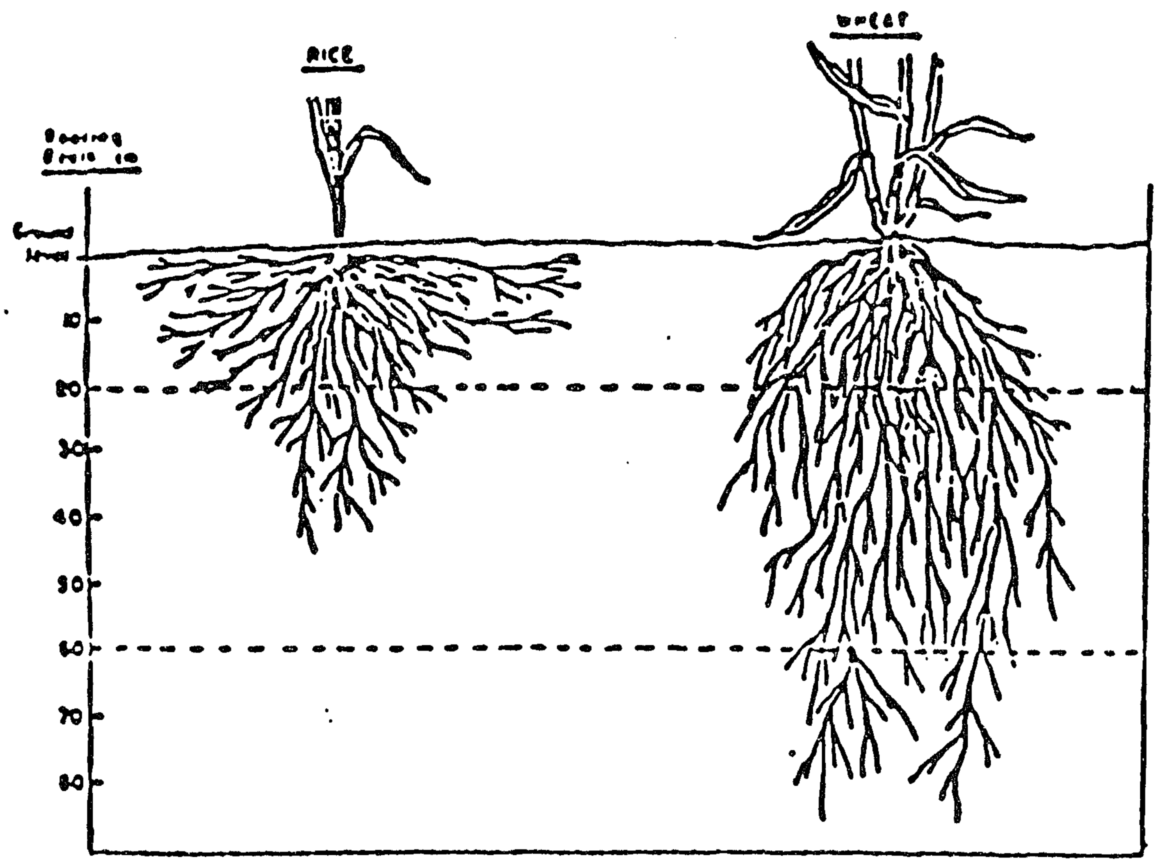


Figure 9. A schematic representation of two different rooting systems.

movement in the soil. And, the use of tracers and modeling has gained acceptance in predicting agricultural chemical movement in soils and aquifers.

2.3.A. Tracer studies in agricultural chemical movement

Conservative tracers have been successfully used to study the movement of chemicals and water in soils and aquifers. Chloride (Cl) and bromide (Br) ions were noted as the most commonly used tracers in previous studies (Davis et al., 1980) because they are safer to handle compared to radioactive tracers (Gamerdinger et al., 1990). However, due to high levels of naturally occurring Cl ions in the aquifers and its characteristic of undergoing anion exclusion especially in finer soils (Jacobs, 1964; Biggar and Nielsen, 1962), Br ion as a tracer is preferred by many researchers. Anion exclusion can account for an increase of 10 to 15 percent in anion tracer velocities (James and Rubin, 1986; Rice et al., 1986). Br is a non-agricultural chemical and its background level in the soil is generally low with values ranging from 5 to 40 microgram per kilogram (Maw et al., 1982; Martin, 1966). It is considered a good and conservative tracer because it does not undergo rapid microbial transformation nor does it quickly bind with the organic matter and clay minerals. Br behaves as a non-interacting solute thereby mimicking the flow of water in the soil system. Br is non-toxic at low concentration and is inexpensive.

Various studies have been conducted using Br as a conservative tracer to evaluate and monitor groundwater pollution by nitrate-N and pesticides.

Bromide was also used to assess the retention and pathways of water and solute movement due to impact of irrigation and rainfall events (Kanwar, 1990; Smith et al., 1990; Fedler et al., 1989; Blume et al.,1987; Carlan et al., 1985; Owens et al., 1985). Smith and Davis (1974), using soil columns, used Br to indicate the movement of nitrate in soils. They found that the movement of Br ions in the subsoil was similar as that of nitrate movement. Their result was confirmed by the field study conducted by Onken et al. (1977) when they studied the movement of Br and nitrate in large irrigated fields.

Carlan et al. (1985) carried out a water movement investigation in the Southern Coastal Plain on a Tifton loamy sand (Plinthic Paleudult) using a Br tracer over a period of 8 weeks under field conditions. They applied water in the treatment wells and took samples along a transect that extended 4 m downslope and 1.5 m upslope from the point of KBr source at intervals of 50 cm to a depth of 3 m. Results from their work indicated that water, as measured by the Br concentration, does not move uniformly through the various soil bodies. They found the highest concentration of Br above the plinthic layer indicating that the water table perches during periods of high soil moisture. Blume et al. (1987) used Br as a tracer to determine water movement in a Tifton loamy sand under natural rainfall condition. Their work showed that the subsurface flow downslope occurred primarily above and within the plinthic horizon when a perched water table was present.

2.3.B. Modeling of agricultural chemical movement

A model is a tool designed to represent a simplified version of reality. Models, if properly constructed, can be valuable predictive tools for the management of agricultural resources. For example, using a chemical transport model, it is possible to test various management schemes and to predict the effects of certain action without the expensive trial and error in actual experimentation. The goal of modeling is usually to predict the value of an unknown variable, say, the concentration of a contaminant over time and space. Good field data is essential when using a model for predictive purposes and the model must have been calibrated and verified. Model testing and calibration, however, were noted to limit model development and utilization. Each model has errors associated with the assumptions relating to the description of the system, choice of equations to represent the system, and input parameters required by the system. And, given these uncertainties associated with models, predictions can not be expected to exactly match point measurements from a field study. The validity of predictions, however, will depend on how well the model approximates the field conditions. Participants of the Predictive Exposure Assessment Workshop in 1982 at Atlanta, Georgia agreed on two criteria for model acceptance (Hedden, 1986). For screening applications of a model, it should be able to match the field observations within an order of magnitude. For site-specific applications (model calibrated with on-site parameters), the model should be able to match the measured field data within a factor of two. An attempt to model a system with inadequate data can also be instructive in that the model may serve to identify those areas where detailed field data are critical to the success of the model. In this way, a model can help guide data collection activities.

Programs that model specific soil - water - pesticide - management combinations have been developed and are continually being improved. Models such as the PRT by Crawford and Donigian (1973), ACTMO by Frere et al. (1975), WASCH by Bruce et al. (1975), CREAMS by Knisel et al. (1980), PESTAN by Enfield et al. (1982), PRZM by Carsel et al. (1985), LEACHMP by Wagenet and Hutson (1986), GLEAMS by Leonard et al. (1987), USBR by Moolman (1988) to name a few, were developed to define the risks of surface and groundwater contamination from agricultural chemical use. None of these models, however, give results of absolute prediction, hence, model application require comparison of known situation to judge the relative effects of the simulation.

2.3.B.1. The GLEAMS model

The GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) is a mathematical model developed for field sized areas to evaluate the effects of agricultural management systems on the movement of agricultural chemicals within and through the root zone (Leonard et al., 1987). It was developed as an extension of the CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel et al., 1980) model. Although the CREAMS model continues to be a useful tool for evaluation of management practices having passed verification and validation tests from varied and extreme conditions (Crowder and Young, 1985; del Vicchio and Knisel, 1982; Nicks et al., 1984; Smith et al., 1978), the many applications of CREAMS have showed areas of weaknesses and applicability from different soil, climatic, topographic, cover, and management interactions (Bengtson et al., 1985; Knisel et al., 1985; Shirmohammadi et al., 1989c). These and the increasing emphasis on pesticides problems and groundwater quality required some modifications in the model to include and consider the more complex root zone groundwater systems, i.e., movement of water and chemicals within and through the root zone. These modifications led to the development of the GLEAMS model as a tool to evaluate the impact of management practices on potential pesticide leaching below the root zone as well as surface runoff and sediment losses from field-sized areas. As with the CREAMS model, the GLEAMS model consists of three major components: hydrology, erosion-sediment yield, and pesticides. Figure 9 shows the physical systems and processes in the GLEAMS model.

The hydrology component uses daily climatic data to estimate runoff volume and peak rate, soil water storage, percolation, and evapotranspiration. Precipitation is partitioned between surface runoff and infiltration into the soil profile. Surface runoff begins when free water surface is generated from the excess rainfall above the infiltration rate. Runoff is estimated using the

USDA Soil Conservation Service (SCS) Curve Number method (1972) as modified by Williams and Nicks (1982). The method relates direct runoff to daily rainfall as a function of a retention parameter, which in turn, is related to soil moisture and the curve number. The curve number is a function of soil type, soil cover, management practices, and antecedent rainfall. Table 6 presents the input data used in the hydrology component simulation.

A storage routing technique is used to simulate redistribution of the infiltrated water within the computational layers through the root zone. The

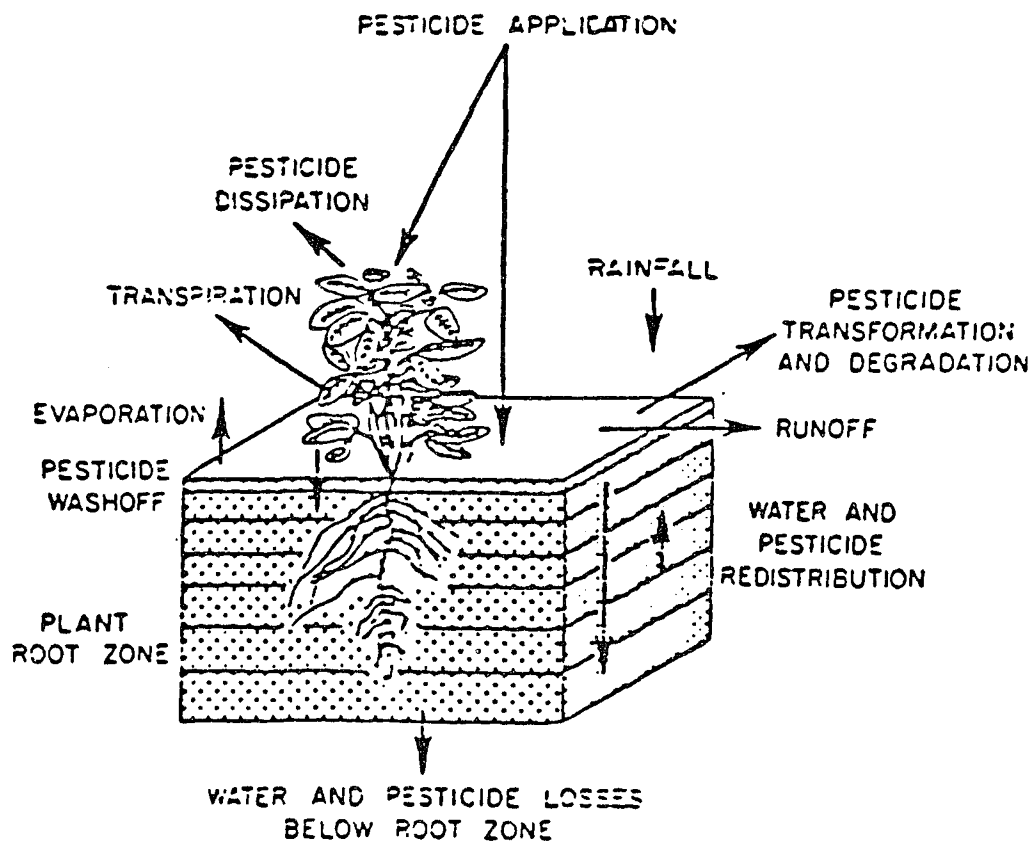


Figure 9. The physical system and processes represented in the GLEAMS model (from Leonard et al., 1987).

technique employs a local water balance method which takes into consideration the soil water content in the previous day and relating it to the amount of infiltrated water in the different layers. Percolation from layers occur when the soil moisture exceed field capacity. The amount of percolation is a function of the hydraulic conductivity and the average soil water content above field capacity which is controlled to some extent by other soil properties. Evapotranspiration is calculated using the modified Penman equation (Ritchie, 1972). This equation calculates soil evaporation and plant transpiration separately in each of the computational layers. Soil evaporation, based on heat flux, is a function of daily net solar radiation and mean daily temperature which are interpolated from a Fourier series fitted to mean monthly radiation and temperature (Knisel et al., 1983). Plant transpiration is computed as a function of potential evaporation and the leaf area index. The sum of evaporation and transpiration is termed as evapotranspiration.

The erosion-sediment yield component uses the modified version of the Universal Soil Loss Equation (USLE) (Wischmeir and Smith, 1978) for storm by storm estimates of rill and interrill erosion in overland flow area. The model calculates sediment loads in the runoff for each field section delineated by a change in slope. It considers the basic processes of soil detachment, transport, and deposition in various combinations of overland flow-channel-pond conditions. The concept of the model is that sediment load is controlled by transport capacity: if sediment load is less than transport capacity, soil

Table 6. User updatable input data required in the GLEAMS hydrology component model simulation (based from the GLEAMS Users Guide (Knisel et al., 1989)).

Data Description	Code	Unit
Drainage area	DAREA	hectare
Soil saturated conductivity	RC	mm/hr
Plant available water in the soil	BST	none
Soil evaporation parameter	CONA	none
SCS Curve Number	CN2	none
Hydraulic slope of the field	CHS	m/m
Ratio of field length to field width	WLW	m/m
Rooting depth	RD	cm
Number of soil horizon	NOSOHZ	none
Depth of each soil horizon	BOTHOR	cm
Porosity of each soil horizon	POR	cc/cc
Field capacity of each soil horizon	FC	cm/cm
Wilting point of each soil horizon	BR15	cm/cm
Organic matter content of each horizon	OM	percent
Mean monthly maximum temperature	TEMPX	degrees C
Mean monthly minimum temperature	TEMPN	degrees C
Mean monthly solar radiation	RAD	langleys
Winter cover factor	GR	none
Leaf area index	AREA	m^2 l/m^2 s

detachment by flow may occur; if, on the other hand, sediment load exceeds transport capacity, deposition occurs. Raindrop impact is assumed to detach particles regardless of whether the sediments are being detached or deposited. Soil erosion and sediment yield are calculated as a function of rainfall intensity, peak runoff rate, runoff volume, soil erodibility, slope, cover, and management factors. Eroded soils are routed with the runoff by particle size (Foster et al., 1985) and the impoundment of water in the fields reduce flow velocity and cause coarse grained primary particles and aggregates to be deposited. And as the sediments are deposited, consequent enrichment of sediments of fine particles are calculated. Table 7 presents the user updatable input data required in the GLEAMS erosion-sediment yield component model simulation.

The pesticide component estimates the concentration of pesticides in the runoff and the total mass carried from layer to layer in the soil profile for each storm during the period of interest. The quantity and concentration of pesticides in both the runoff and in the soil profile are functions of the soil, climate, pesticide properties, and management practices and their interactions. The model divides the crop rootzone into a minimum of three and a maximum of twelve computational layers. The first computational layer has a thickness of 10 mm. The authors observed that there was strong correlation between pesticide concentration in the runoff and in the top 10 mm of the soil profile (Leonard et al., 1988). The subsequent computational layers consider a 10 cm maximum thickness equally divided within each soil horizon. The model can accommodate up to 10 pesticides simultaneously. This feature

Table 7. User updatable input data required in the GLEAMS erosion-sediment yield component model simulation (from GLEAMS Users Guide (Knisel et al., 1989).

Data Description	Code	Unit
Number of sediment particle types	NPART	none
Fraction of clay in the surface layer	SOLCLY	percent
Fraction of silt in the surface layer	SOLSLT	percent
Fraction of sand in the surface layer	SOLSND	percent
Specific surface area of clay particles	SSCLY	m^2/g
Specific surface area for organic matter	SSORG	m^2/g
Number of points for overland flow slope	NPTSO	none
Drainage area represented by overland flow profile	DAOVR	hectare
Distance from upper end of overflow profile to point where slope is given	XOV	meter
Slope of overland flow profile	SLOV	m/m
Number of slope segment differentiated by changes in erodibility factor	NXK	none
Relative distance from top of slope to bottom of segment	XSOIL	none
Erodibility factor for the segment	KSOIL	t/hectare/EI
Number of years in rotation	NYEARS	none

makes possible the observation of the effect of changes in pesticide properties, i.e., partition coefficients on resulting leaching losses with one run of the model. Table 8 presents the user updatable input data required in the GLEAMS pesticide component model simulation.

Table 8. User updatable input data required in the GLEAMS pesticide component model simulation (from GLEAMS Users Guide (Knisel et al., 1989).

Data Description	Code	Unit
Number of pesticides considered in simulation	NPEST	none
Pesticide name	PSTNAM	none
Number of metabolite of particular pesticide	METAB	var
Water solubility of pesticide considered	H_2OSOL	mg/L
Foliar residue half-life	HAFLIF	days
Partition coefficient of pesticide considered	KOC	none
Concentration of pesticide residue on foliage	FOLRES	ppm
Coefficient of transformation from parent compound to metabolite to metabolite	COFUP	none
Soil half-life of pesticide considered	SOLLIF	days
Pesticide residue on soil horizon	RESDUE	µg/g
Number of pesticide applied on PDATE	IPST	none
Pesticide identification number	NOPEST	none
Rate of application of active ingredient	APRATE	kg/hectare
Depth of incorporation	DEPINC	cm
Fraction of pesticide applied to foliage	FOLFRC	percent
Fraction of pesticide applied to soil	SOLFRC	percent
Method of application	METH	var

CHAPTER 3

MATERIALS AND METHODS

3.1. The research area

The research area is located on the Louisiana Agricultural Experiment Station's Ben Hur Research Farm. The Farm is situated about 6 km south of Baton Rouge, Louisiana on the broad natural levee of the Mississippi River floodplain (Figure 10). The area is characterized by a nearly level topography. Two soils comprised the research area: the Mhoon series (fine-silty, mixed, nonacid, thermic Typic Fluvaquents) and the Commerce series (fine-silty, mixed, nonacid, thermic Aeric Fluvaquents). These soils are common and occupy large portions of the agricultural lands in the Lower Mississippi Valley. The soils in the research area were formed by alluvium deposited by the meandering of the Mississippi River. The Mhoon soils closely resemble the Commerce soils but are more poorly drained. A more detailed description of these soils are found in Schumacher et al. (1988) and in Dance et al. (1968).

The climate of the area is considered humid sub-tropical. The annual average temperature is 19.8 degrees Celsius and the annual average relative humidity is 73 percent. During summer, the average high temperature is 32.6 degrees Celsius and the average relative humidity is 80 percent or greater for 50 percent of the time. Temperature variations occur due to the

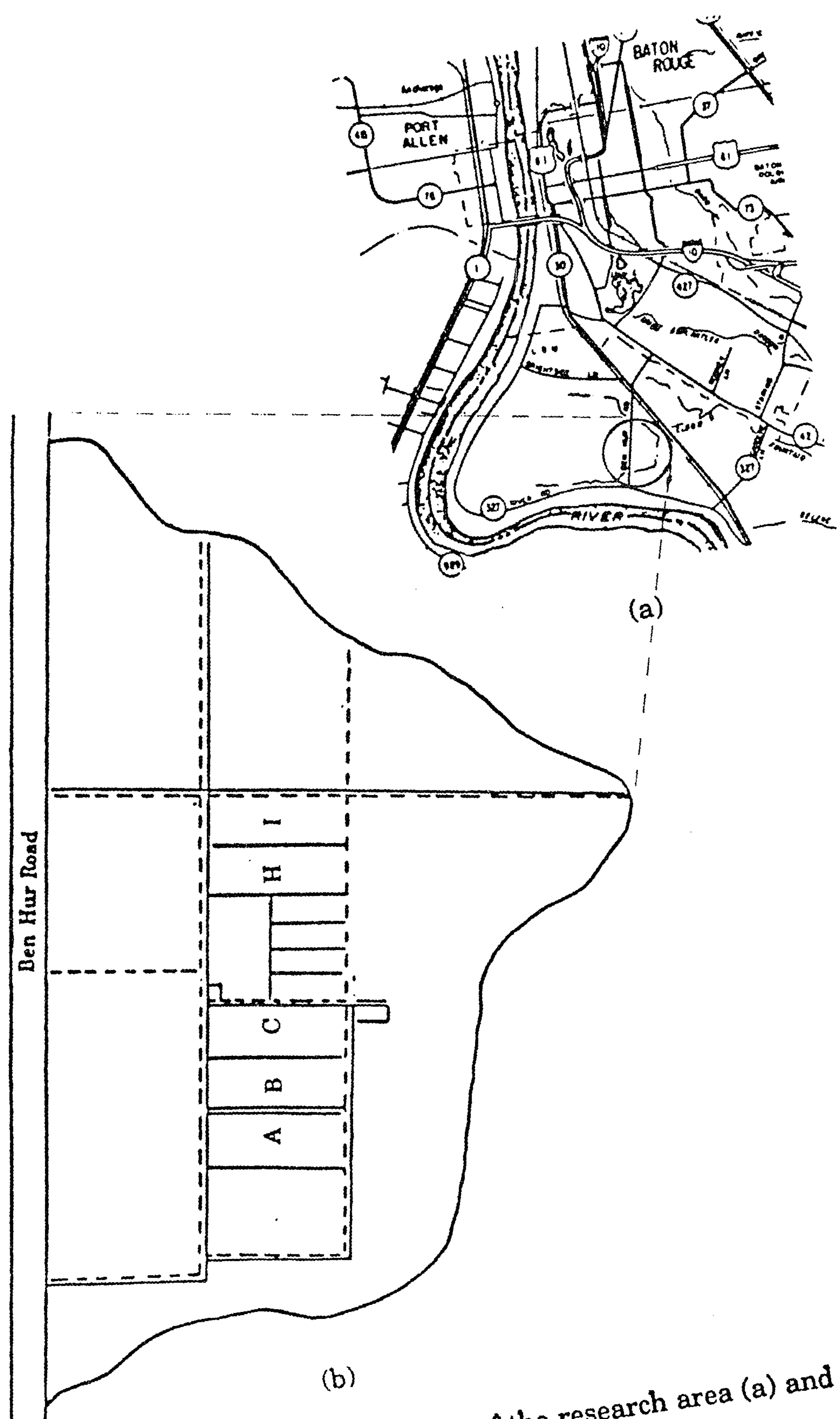


Figure 10. Map showing the location of the research area (a) and the layout of the experimental plots (b).

modifying influence of the warm, moist, tropical air generally originating from the nearby Gulf of Mexico. The normal annual precipitation is 1450 mm and may occasionally exceed 2000 mm. Heavy showers and general rains usually last no more than a few hours and can produce local flooding and excessive moisture conditions in the area. The annual evapotranspiration is approximately 1000 mm; thus, the annual rainfall surplus ranges from about 450 to 1000 mm.

Five relatively flat plots were used in the experiment. Figure 11 shows the layout of the experimental plots including the location of the instruments. The area of each plot ranges from 3.37 ha to 3.71 ha and the slope of the plots ranges from 0.1 to 0.16 percent. Each plot was bordered by a 30-cm levee to separate the runoff from one plot to another and to direct the runoff to the H-flume installed at the lower end of each plot. Based from the soil survey conducted, the characteristics of the soils in the experimental plots resembles the characteristics typical of Commerce silty clay loam soil. The surface layer is a dark brown, moderately fine silty clay loam which extends from the surface to a depth of about 11 cm. It is underlain by dark grayish brown clay loam to a depth of 20 cm. The next lower horizon is of clay loam texture which extends to about 58 cm and the subsequent soil horizon down to 109 cm is of silt loam texture. Further, the soil horizon of loamy clay texture extends down to 152 cm and furthermore, a clay texture to a depth of 186 cm below the ground surface. The detailed profile description of the Commerce silty

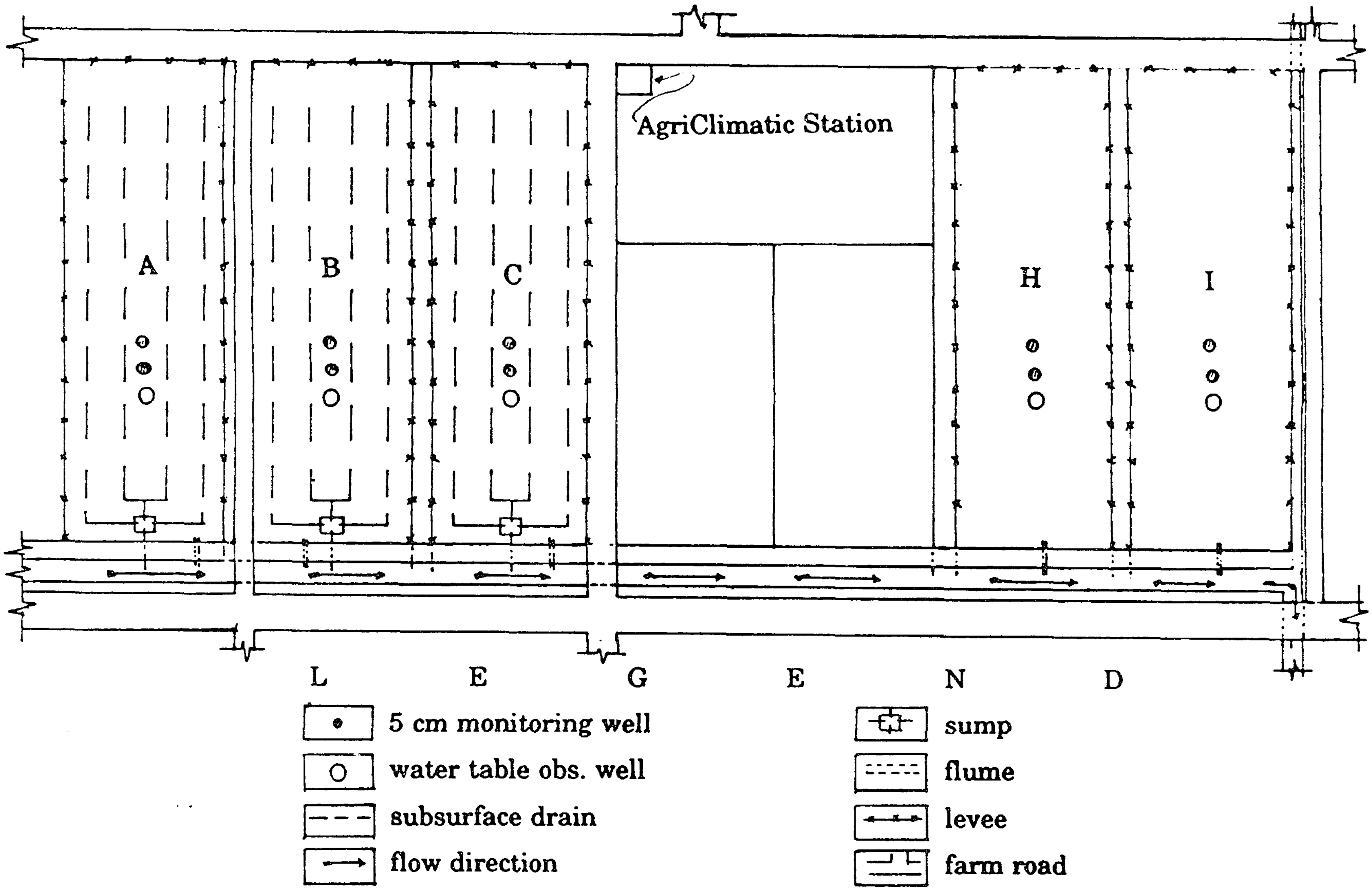


Figure 11. Layout of the experimental plots showing the instrumentations.

clay loam soil in the experimental plots is presented in Table 9. This soil is somewhat poorly drained and moderately slowly permeable. It has a saturated hydraulic conductivity of approximately 1 mm/hr from just below plow depth (approximately 10 cm) down to about 60 cm. Between 60 cm and 130 cm depth, there is a layer that has a saturated hydraulic conductivity of up to 80 mm/hr (Rogers et al., 1985). The experimental plots had been planted continuously to corn (*Zea Maize L.*) from 1981 to 1987 and were planted to soybeans [*Glycine max (L.) Merr.*] from 1988 to 1992.

3.2. Instrumentation in the experimental plots

A 61 cm H-flume, designed to collect and measure the surface runoff, was installed at the lower end of each plot. Surface runoff depth in the flume was measured with an FW-1 water stage recorder. The water level in the flume was continuously charted during each surface runoff event through a float connected to a charting mechanism. Runoff volumes from each plot were calculated from the developed runoff hydrograph. Each runoff event was sampled by an automatic water sampler (ISCO Model No. 1640) installed at each flume. The samples were taken every twenty minutes during an event. The runoff samplers, each with twenty eight 600-ml sampling bottles, were capable of sampling runoff events up to 9 hours of runoff. Sensors placed at designed levels (0.25 ft) above the flume floor automatically activated the samplers when submerged. To insure that the samples taken reflected an accurate representation of the amount of eroded sediments in the runoff, the

Table 9. A detailed profile description of the Commerce silty clay loam soil in the experimental plots (based from Schumacher et al., 1988).

Classification: Fine-silty, mixed, nonacid, thermic Aeric Fluvaquent;

Geographical setting: On the higher part of natural levee on the Mississippi River alluvial plain;

Drainage and permeability: Somewhat poorly drained; moderately slowly permeable;

Profile description:

Ap1	0 - 11 cm; dark brown (10 YR 4/3) silty clay loam; moderate fine granular structure; very friable; many fine and very fine roots; slightly acid (pH 6.1); gradual diffuse boundary;
Ap2	11 - 20 cm; dark grayish brown (10 YR 4/2) clay loam; few, fine, faint dark yellowish brown (10 YR 4/4) mottles; moderate, fine sub-angular blocky structure; friable; many fine roots; midly acid (pH 6.6); gradual wavy boundary;
Bg	20 - 58 cm; grayish brown (10 YR 5/2) clay loam; common, medium, distinct, clear dark yellowish brown (10 YR 4/4) mottles; moderate medium sub-angular blocky structure; firm; few fine roots; neutral (pH 7.0); clear smooth bondary;
C1	58 - 109 cm; grayish brown (10 YR 5/2) silt loam; common; medium, distinct, clear yellowish brown (10 YR 5/5) mottles; weak, medium, sub-angular blocky structure; friable; midly alkaline (pH 7.3); clear smooth boundary;
C2	109 - 152 cm; grayish brown (10 YR 5/2) loamy clay; common, medium, distinct, clear dark yellowish brown (10 YR 5/6) mottles; massive; saturated; midly alkaline (pH 7.6); gradual wavy boundary;
C3	152 - 186 cm; dark grayish brown (10 YR 4/2) clay; many, medium, distinct, clear dark yellowish brown (10 YR 5/6) mottles; massive; saturated; midly alkaline (pH 7.7); gradual diffuse boundary.

flume was designed so that a hydraulic jump developed in the flow to agitate and provide proper mixing of the runoff. Sample containers were collected from the samplers the day following a major runoff event or a maximum of five days after a runoff-producing rain occurred. This procedure was to make certain that sampling bottles were available for the next runoff event.

Water table elevations were continuously measured from a cased water table monitoring well installed in each of the plots. An FW-1 water stage recorder mounted above the cased monitoring well was equipped with a graduated float tape that passed over the float wheel and had the ends attached by ring to a float on one end and to a counterweight on the other end. The graduated tape and index pointer enabled the observer to check the pen reading against water level in the well. Water table data from the stage recorders were digitized and transferred to magnetic tapes with a digitizer equipped plotter. The observed water table data in "break-point" form were interpolated and transformed to daily water table depth. The observed daily water table depth and daily precipitation in each of the plots during the study period are listed in Appendix A.

Two 5.1 cm diameter schedule 40 PVC tubes, one at 1 m depth and the other at 2 m depth, were installed on December 20, 1990 in each of the experimental plots to sample the water table. A lenght of 30.5 cm was perforated at one end of each tube to allow entry of water from the soil profile. The perforated length was wrapped with polyester filter fabric to minimize the clogging of the perforations by fine particles of silt or clay. Wells were bored using a 7.5 cm diameter hollow stemmed soil auger to the specified depths in each plot. The tubes were installed by pushing the tubes with the perforated end down the bore until seated on the bottom and back-filling the bore with the excavated clayey materials to seal and avoid entry of water from the soil surface. The lower end of the tube was open while the upper end, which was extended 32.5 cm above the soil surface, was capped. The tubes were placed in each plot 3.5 m west of the cased water table monitoring wells. The sampling tube wells were spaced 3.5 m apart to avoid water table disturbance in one tube while sampling the other tube.

Three plots, A,B, and C in Figure 11, were subsurface drained and two plots, H and I in Figure 11, were not. Four 104 mm diameter corrugated and perforated drain tubes were installed one meter below the soil surface on a grade of 0.1 per cent and 30 m apart. The subsurface drain outflow from each plot was directed to a 1.2 m x 1.2 m x 3.0 m metal sump equipped with an electric pump for discharging the outflow into a surface drainage ditch. The outflow from the two center subsurface drains was measured and sampled. The quantity of the subsurface outflow was measured with water meters installed in the outlet line from the pump. An automatic water sampler (ISCO Model No. 1640) was used to sample the outflow. The plots with and without subsurface drainage will be referred to as drained and nondrained plots, respectively, in this study.

Climate data such as rainfall, temperature, solar radiation and relative humidity were measured and recorded at the agriclimatic station near the experimental plots. Rainfall was measured with a weighing type recording raingage (Sierra Misco Model RG2501); temperature and relative humidity were measured with hygrothermograph (RMS Technologies- NWS issue); and solar radiation was measured with a pyranograph (LI-COR Model LI-200SB). Recording of agriclimatic data was automated using Campbell CR-21X computer. Climate data files are maintained by the Louisiana AgriClimatic Information Systems of the LSU Agricultural Center.

3.3. Field tracer experiment

A field tracer monitoring experiment was conducted from March 8, 1991 to November 5, 1992 in the five plots. One kilogram of crystalline potassium bromide (KBr) was applied on March 8, 1991 on one square meter area sorrounding each of the monitoring wells. The KBr was applied in the surface soil and later mixed with the soil by hoeing. The chemical, being highly water soluble, was expected to readily dissolve and move with the surface runoff and infiltrate into the soil profile and onto the water table when it rains.

The monitoring wells were sampled within 2 days following each runoff-producing rain event to determine whether the infiltrated water, if any, had reached the water table. Runoff generally occured after soil surface storage and soil infiltration requirements were satisfied and the pore spaces were filled with water. A 500 ml sample was collected from each of the monitoring wells using a small peristaltic pump. A Tygon plastic tubing was used to connect the hand pump to a receiving glass bottle while another plastic tube connected from the glass bottle was used to bring the water up from the sampling point in the monitoring tube. The hand pump operated through differential pressures between the collection bottle and the atmospheric pressure in the monitoring tube. Sampling point was at the bottom of each monitoring tube. The initial water taken from the well was used to rinse the receiving bottle, stopper and the plastic tubings.

A portion of the 500 ml sample was placed in a separate plastic bottle for use in the analyses of the tracer concentrations and the remaining part was used in the analyses of pesticide species. Separation of the sample was done by filtering about 100 ml from the 500 ml sample with a 0.45 micron filter membrane. The samples were stored in a freezer until ready for analysis. Samples for the tracer analysis were diluted with deionized water when necessary so that the Br concentrations were within the detection range. The analysis for ions were conducted at the Soil Chemistry Laboratory of the LSU Department of Agronomy with an ion chromatograph (Dionex 250) using the methods as described by Feagly et al. (1991).

3.4. Herbicide monitoring study

Simultaneous with the tracer experiment, samples of water were collected to determine the concentrations of the herbicides trifluralin, metolachlor, and metribuzin in the runoff, outflow, and water table from the experimental plots for two cropping seasons (1991 and 1992). These herbicides were applied to the land to eradicate the weeds from the soybean fields. A 48.04% emulsifiable concentrate of trifluralin (Treflan EC) was applied using a tractor-mounted boom sprayer to Plots A, B, C, and H to give 1,683 grams per hectare. Turbo 8EC containing 78.67% metolachlor and 17.41% metribuzin was applied to give 2,757 grams per hectare metolachlor and 609 grams per hectare metribuzin at Plot I. The same rates of application were applied in both cropping seasons. The experiment was conducted in conjunction with the cropping program of the Ben Hur Research Farm. The herbicide applications were performed by the Farm's personnel and the researcher did not have a direct hand in the applications.

Water samples from the flumes and sumps were collected to quantify the amount of herbicides in the runoff and the subsurface drain outflow. The automatic water sampler installed in the flume took 500 ml sample every 20-minute intervals during each runoff event. The samples from the flume were composited and the required amount for analysis was saved and stored at freezing temperature until ready for analysis. The automatic water sampler at the sumps took 125 ml sample every 3 hours during subsurface discharge. Samples were collected every 10 to 12 days. Composite samples adequate enough for the required analysis were taken from the sump samples for analysis. These water samples were analysed for each of the herbicide species using ECD gas chromatography.

Composite soil samples from 0-15 cm depth were collected from each plot one day before and after the herbicide application and every week thereafter to determine the degradation time of the herbicides. In order to determine the leaching potential of the herbicides, composite soil samples by depth (0-5 cm, 5-10 cm, 10-15 cm, 15-30 cm, and 30-60 cm) were collected from each plot one month and two months after the herbicides were applied. The composite soil samples were air dried and ground to pass a 2 mm sieve. The samples were stored at room temperature until ready for analyses. Extraction and analyses were conducted at the USDA Soil and Water Laboratory. Herbicide analysis on the water extracts from the soil samples were done following the same procedures which were used in the analysis of water extracts from the water samples. The pesticide species were analysed at the USDA Soil and Water Laboratory using ECD gas chromatography. Pesticide analyses were done using the method as described by Southwick et al. (1990) except that the columns used were relevant to the pesticide species being analyzed.

3.5. Model simulation

The GLEAMS model was used in the simulation of the fate and movement of the applied herbicides in the experimental plots. The model uses five types of input data: 1) climatological: precipitation, temperature, and solar radiation; 2) soils: texture, porosity, hydraulic conductivity, field capacity, wilting point, and bulk density; 3) crop: rooting depth and leaf area; 4) topographical: field slopes and extent and field channels; and 5) farm management: tillage, soil cover, and fertilizers and pesticides type and mode of application. In the absence of measured data the best available estimates on required input parameters were obtained from the user's manual or other available literature. The estimates were entered into the input parameter files following the GLEAMS User's Guide (Knisel et al., 1989). The model was not calibrated to the data in any way. The parameter files were then inputted into the model. Model simulation was performed for the years 1991 and 1992.

Table 10 presents some selected soil physical properties used in the preparation of the parameter input files. Tables 11 and 12 presents the daily precipitation (cm) in the experimental site for 1991 and 1992, respectively, in the GLEAMS required format used in the model simulation. Tables 11 and 12 are composed of 37 cards per year with 10 values per card (ten 5-column fields, column 11-60). The first 10 columns and the last 20 columns (61-80) were identification data and were not read by the model. The Read format for the rainfall input file by GLEAMS was: 10X, 10F5.2, 20X. A full year's set of 37 cards was necessary for each year of simulation even though the simulation can begin on any specified day during the year. Zero values i.e., fields 6-10 on card 37 were used to represent values during unmeasured periods.

Tables 13, 14, and 15, respectively, presents an example of the input data in GLEAMS parameter file format used in the simulation of hydrology, erosion-sediment yield, and pesticide components, respectively. The hydrology

Table 10. Some selected hydrologic and soil parameters of the experimental plots used in the preparation of the GLEAMS parameter input files.

Soil Properties	Value
Texture, top soil	Silty Clay Loam
Texture, sub-soil	Clay loam
Porosity, %	0.47
Bulk density, g/cm^3	1.41
Field capacity at 1/3 bar, surface layer, cm/cm	0.36
Wilting point at 15 bar, surface layer, cm/cm	0.14
Depth, surface layer, cm	11
Depth, sub-surface layer, cm	52
Depth, maximum growth layer, cm	110
Sat. hydraulic conductivity, surface layer, cm/hr	0.10
Sat. hydraulic conductivity, subsurface layer, cm/hr	10
Soil erodibility factor	0.63
Organic carbon content, surface layer, %	1.14
Organic carbon content, sub-surface layer, %	0.63
Sand content, %	36
Silt content, %	31
Clay content, %	33
pH	slightly acidic

input parameter file (Table 13) was composed of 19 cards with ten 8-column fields except for the title cards (cards 1-3) with 80-character lines per card of alphanumeric information that identifies the particular computer run. Each card lists the data appropriate for the respective parameters i.e., card 4 gives the beginning date for the simulation in the first field, the code for output type in the second field, the code for irrigation in the third field, etc.; card 6 contains the drainage area in the first field, the effective saturated conductivity in the next field, fraction of available water in the soil in the next field, etc.. Likewise, the input parameter files for the erosion-sediment yield (Table 14) and the pesticide component input parameter files (Table 15) provides the model with the appropriate data (see Tables 6, 7, and 8) for the simulation. The reader is advised to refer to the GLEAMS Users' Manual for instructions in developing the input parameter files. Some outputs from the simulation of one component served as input to the other components; for example, peak runoff rate from the hydrology component was used as input to the erosion component and the enrichment ratios from the erosion component as input to the pesticide component.

Table 11. Daily precipitation (cm) in the experimental site in the GLEAMS required format used in the model simulation for 1991.

1991	0.05	0.33	0.63	0.00	0.00	1.68	0.00	0.03	0.08	8.25	01
	0.05	0.00	0.00	0.00	1.03	0.00	0.08	1.25	0.00	0.00	02
	0.00	0.00	1.80	1.78	0.00	0.00	1.25	0.00	0.83	0.90	03
	0.00	0.00	0.00	0.00	0.13	4.50	0.00	0.00	0.00	0.00	04
	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	1.90	05
	4.63	4.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.48	06
	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	07
	0.00	0.00	0.00	0.28	3.30	0.35	0.13	0.00	0.00	0.00	08
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.00	0.00	09
	0.00	0.00	0.00	0.00	0.00	0.10	1.00	0.00	0.00	0.25	10
	0.03	0.00	0.00	4.18	0.00	0.10	0.73	2.78	0.80	0.00	11
	0.00	0.00	0.30	0.05	0.75	2.20	0.00	2.23	7.50	0.05	12
	0.00	3.03	0.00	3.10	0.05	0.00	1.50	11.55	2.70	3.48	13
	0.00	0.00	0.00	0.03	2.15	0.00	2.25	1.18	0.55	1.25	14
	0.35	0.03	0.35	0.03	0.98	0.00	0.33	0.00	0.08	0.68	15
	0.00	0.00	0.00	0.00	0.00	5.00	4.53	0.00	0.00	0.00	16
	0.65	2.18	0.60	0.08	0.00	0.00	0.00	0.60	5.18	0.00	17
	0.00	0.00	0.53	0.00	1.58	0.00	0.00	0.58	0.00	0.03	18
	0.00	0.00	0.43	0.00	5.53	0.45	2.35	2.73	0.18	0.53	19
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20
	0.00	0.00	0.03	0.00	0.00	1.25	0.03	0.00	0.00	0.00	21
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.23	22
	0.03	1.40	0.03	0.00	0.00	0.23	0.00	0.00	0.00	0.00	23
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.85	0.05	24
	0.00	5.00	0.23	0.03	1.35	0.00	0.05	0.45	0.03	1.13	25
	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	26
	0.00	0.63	0.00	0.00	0.00	1.80	0.85	0.08	0.00	0.00	27
	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	28
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29
	0.00	0.00	0.00	0.00	1.83	1.18	0.00	0.00	5.65	0.35	30
	0.10	0.15	0.33	0.75	0.33	0.00	0.00	0.00	0.00	0.00	31
	0.25	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32
	0.00	0.00	0.78	2.40	0.08	0.03	0.00	0.00	0.00	0.00	33
	0.00	0.00	0.15	0.00	0.73	0.88	0.00	0.00	0.00	0.00	34
	0.00	0.03	1.30	0.00	0.00	0.00	1.15	0.15	0.00	0.00	35
	0.00	0.00	0.00	0.00	0.00	0.05	0.50	0.00	0.00	0.00	36
	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37

Table 12. Daily precipitation (cm) in the experimental site in the GLEAMS required format used in the model simulation for 1992.

1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.98	0.03	0.00	01
	0.00	2.93	0.01	0.00	0.00	0.00	0.15	7.75	0.00	0.00	02
	0.00	3.95	0.00	0.00	0.00	0.00	4.20	3.23	0.08	0.00	03
	0.00	0.00	0.00	0.00	6.78	0.33	0.00	0.00	0.00	0.00	04
	0.00	0.00	0.08	2.53	2.63	6.25	0.70	1.85	0.00	0.00	05
	0.00	0.00	1.60	0.00	0.05	0.05	0.00	0.00	0.00	0.00	06
	0.00	0.00	0.00	0.00	6.88	0.00	0.00	0.00	0.58	0.38	07
	0.00	0.00	0.00	0.00	0.00	0.00	0.03	2.00	0.00	0.00	08
	0.23	0.78	0.00	0.00	0.10	0.00	0.00	0.48	0.58	0.00	09
	0.00	0.00	0.00	0.00	0.00	0.25	1.20	0.00	0.00	0.00	10
	0.45	0.00	0.00	3.48	0.00	0.00	0.13	0.48	0.15	0.00	11
	0.35	0.00	0.00	0.10	0.43	0.80	0.00	0.00	0.00	0.33	12
	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	13
	0.00	0.00	0.30	0.00	0.00	0.00	0.35	0.03	0.03	0.00	14
	0.00	0.00	0.00	0.60	0.00	0.00	2.13	2.45	0.88	0.13	15
	0.00	0.18	0.10	3.70	0.83	0.03	0.00	0.08	2.08	0.40	16
	0.05	0.00	2.25	1.60	1.20	0.18	0.00	0.00	0.38	0.03	17
	0.55	0.28	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.00	18
	0.05	13.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19
	0.05	3.70	0.00	0.00	0.00	0.00	0.10	0.23	0.15	0.28	20
	0.03	1.03	0.15	1.73	6.20	1.55	0.00	0.03	0.00	0.50	21
	0.00	0.75	0.13	3.40	0.00	0.00	0.00	0.03	0.00	0.03	22
	0.00	0.10	0.05	0.00	0.33	0.73	0.15	0.00	0.00	0.00	23
	0.00	0.00	0.00	0.00	1.83	0.65	0.40	1.05	5.63	0.00	24
	0.00	0.00	0.00	0.00	0.03	0.00	1.13	0.00	0.00	4.73	25
	2.15	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.03	26
	0.30	0.00	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00	27
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28
	0.00	0.00	0.00	0.08	1.83	0.00	0.00	0.00	0.00	1.23	29
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30
	4.50	0.03	0.00	1.88	0.00	1.63	0.00	0.35	4.28	0.00	31
	0.00	0.00	0.00	0.00	2.93	3.78	0.00	0.00	0.00	0.00	32
	0.00	0.00	0.08	2.93	0.93	0.00	0.85	0.45	0.00	0.00	33
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.05	34
	0.08	0.00	0.00	2.75	0.00	0.00	0.00	0.00	0.00	3.90	35
	0.73	0.00	0.00	0.53	0.18	0.00	0.00	0.08	0.25	0.03	36
	0.35	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37

Table 13. An example of the hydrology component input parameter file used in the GLEAMS model simulation.

```
Ben Hur Research Farm, Plot A
Baton Rouge Louisiana
Hydrology Component Worksheet
 91001      0      0      0      1      0      1      0      0      0
  3.71     .1    .95    4.0     85  .0014  3.025  110.0
     5   11.0   20.0   58.0   86.0  110.0
  0.47    .40    .40    .43    .43
  0.36    .35    .35    .32    .32
  0.20    .22    .22    .12    .12
  1.14    .85    .63    .46    .37
  15.8   19.6   22.3   26.2   28.4   31.2   32.5   32.3   29.8   27.4
  19.5   18.9
   5.3    6.8   11.2   16.6   21.0   22.5   23.3   22.6   19.9   14.6
   5.9    7.9
 265.6  290.2  313.2  309.0  403.2  487.9  478.8  398.6  388.7  318.2
 246.5  168.8
    .5
   001
   114    .00
   132    .12
   150    .33
   166    .00
   179    .12
   192    .33
   205   1.58
   218   2.16
   220   2.49
   243   2.46
   256   2.42
   269   1.91
   282    .95
   295    .41
   366
    -1      0      0
```

Table 14. An example of the erosion-sediment yield component input parameter file used in the GLEAMS model simulation.

```
Ben Hur Research Farm, Plot A
Baton Rouge Louisiana
Erosion-Sediment Yield Component Worksheet
   91     91     3    0     1     0      91001     1
  .33    .31   .36  800.0 1000.0
   1   3.71
 335.0  .0014
   1    1.0   .63
   1
  001     11     52     77    105    158    163    187    241    301
   1    1.0
  .85    .85    .85    .85    .85    .85    .85    .85    .85    .85
  1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0
 0.022  .022   .022   .022   .022   .022   .022   .022   .022   .022
```

Table 15. An example of the pesticide component input parameter file used in the GLEAMS model simulation

```
Ben Hur Research Farm, Plot A
Baton Rouge, Louisiana
Pesticide Component Worksheet
 91154      92365      1     1     3
   1      Treflan      0
   1    0.3   20.0   875.0   0.0   .00   0.0   .18
  10.0  46.0  46.0   46.0   46.0   .05   .05   .04   .02   0.0
  1155
   1  1.683   1.0    0.0    .8     1    0.0
   0
```

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Precipitation, drainage, and response of the water table

Precipitation, drainage, and the response of the water table represent the dominant factors that influence the fate and movement of agricultural chemicals in the soil profile. Precipitation serves as the source of solvent and provide the impetus in the chemical movement; drainage indicates the chemical pathways; and the response of the water table to the precipitation demonstrates the behavior of the soil and water in the field and hence, the fate and movement of agricultural chemicals.

4.1.A. Precipitation

Large amounts of precipitation occurred at the study area during the experimental period. The annual rainfall in 1991 totaled 1810 mm which was 27 percent higher than to the total long term average precipitation of 1,427 mm. Similarly, rainfall in 1992, with an annual total of 1,855 mm, was 30 percent more than the long term normal rainfall. The precipitation was not evenly distributed throughout the year. The rainfall in both 1991 and 1992 were high during some months reaching 2.8 and 3.5 times the normal rainfall amounts in May 1991 and June 1992, respectively. In some months, however, the precipitation was very low, i.e., 41 percent of normal rainfall in December 1991 and 57 and 59 percent of normal rainfall in April and May 1992, respectively. Normally, higher amounts of rainfall occur during the months of July, April, August, and December in descending order. The largest amount of rainfall in 1991 occurred in May followed by the months of April, June, and January, respectively. In 1992, the highest rainfall occurred in January followed by June, February, and November in descending order. The variability in the observed monthly rainfall in both 1991 and 1992 indicates a difficulty in predicting the seasonal rainfall pattern in the research area. The observed monthly and annual precipitation are presented in Table 16.

4.1.B. Drainage

The large amounts of precipitation coupled by low evaporative demand produced large amounts of drainage (runoff and subsurface outflow) from the experimental plots. Runoff generally occurred after the soil surface storage, evapotranspiration, and infiltration requirements were satisfied. The average annual drainage from the experimental plots was 962 mm (53% of the annual rainfall) in 1991 while it was 1,106 mm (59% of the annual rainfall) in 1992.

The average monthly surface and subsurface outflow from the experimental plots in 1991 and 1992 are listed in Table 17. The average monthly surface runoff from the drained plots were substantially lower than those from the nondrained plots in 1991 and 1992. The annual drainage, however, was larger in the drained plots compared with the annual drainage from the nondrained plots. The difference can be attributed to the subsurface drains installed in the drained plots. The drains reduced the

Table 16. Observed monthly and annual precipitation in the research area (from the Louisiana AgriClimatic Information System).

Month	Normal* Rainfall Amount (mm)	1991		1992	
		Observed Rainfall (mm)	% of Normal Rainfall	Observed Rainfall (mm)	% of Normal Rainfall
January	116.3	200.2	172	294.0	253
February	126.2	154.7	123	228.5	181
March	116.6	143.7	123	120.4	103
April	142.0	230.5	162	81.5	57
May	122.4	343.0	280	72.6	59
June	79.0	215.4	273	278.1	352
July	179.6	135.1	75	166.1	92
August	128.3	121.8	95	143.8	112
September	122.3	65.6	54	96.7	79
October	66.8	103.9	156	95.5	143
November	100.3	43.7	44	182.1	182
December	126.8	52.4	41	95.4	75
Annual	1426.6	1810.0	127	1854.7	130

* Long term average (32 years of records)

the annual surface runoff by 28% in 1991 and 27% per cent in 1992. The total surface runoff from the drained plots was 613 mm (34% of the annual rainfall) while the total runoff from the nondrained plots was 854 mm (47% of the annual rainfall) in 1991 or a difference of 241 mm. In 1992, the total surface runoff from the drained plots was 769 mm (41% of the rainfall) and that from

Table 17. Average monthly surface and subsurface outflow from the experimental plots in 1991 and 1992.

Month/ Year	1991				1992			
	Drained Plots**			Nondrained Plots Runoff* (mm)	Drained Plots**			Nondrained Plots Runoff* (mm)
	Runoff (mm)	Subsurface (mm)	Total (mm)		Runoff (mm)	Subsurface (mm)	Total (mm)	
January	57.5	85.1	142.6	133.4	130.2	103.3	233.5	194.6
February	61.8	51.2	113.0	104.4	157.8	86.2	244.0	197.8
March	59.9	48.0	107.9	74.4	39.1	43.0	82.2	63.1
April	93.3	74.0	167.3	129.8	5.1	11.7	16.8	7.4
May	187.0	127.3	314.3	255.4	0.4	0.2	0.5	1.9
June	91.1	33.8	124.9	125.4	118.6	60.3	178.8	152.3
July	46.0	30.8	76.8	101.4	65.7	31.1	96.8	91.2
August	10.1	0.1	10.2	29.2	128.8	0.6	129.3	143.7
September	0.7	1.3	2.0	3.0	25.9	8.2	34.1	45.5
October	4.8	0.1	4.9	20.3	5.2	4.9	10.1	5.6
November	0.6	0.5	1.1	1.8	67.0	27.5	94.5	105.1
December	0.1	3.9	4.0	1.0	25.4	7.9	33.4	49.9
Annual	612.8	456.0	1068.8	854.2	769.3	384.8	1154.1	1058.2

** Average of plots A, B, and C. * - Average of plots H and I.

the nondrained plots was 1,058 mm (57% of the annual rainfall). The months of May, April, and June (in descending order) have the most surface runoff in 1991 while the months of February, January, August, and June gave the most surface runoff in 1992 (Table 17). The average surface runoff from the drained plots ranged from 0.1 mm (December, 1991) to 187 mm (May 1991) while those from the nondrained plots ranged from 1.0 mm to 255 mm (Table 17). In 1992, the average surface runoff from the drained plots ranged from 0.4 mm (May) to 158 mm (February) and the nondrained plots yielded 2 mm (May) to 198 mm (February) (Table 17).

Consequent with surface runoff is the amount of soil lost from the experimental plots. Since soil erosion is primarily caused by surface runoff, the amount of soil loss is directly proportional to the volume of runoff. And, not only the amount of soil loss through the runoff is of importance but also the amount of nutrients and chemicals adsorbed to the eroded sediments. The composition and concentration of dissolved materials contained in the surface drainage waters represent an amount which may contaminate the surface water system. On the other hand, the amount of chemicals in the runoff decreases the amount of chemicals in the soil profile susceptible to leaching. Table 18 presents the average monthly soil loss from the experimental plots in 1991 and 1992. The soil loss from the nondrained plots were substantially higher compared to the soil loss from the drained plots and were consistent with the amount of surface runoff volume. Soil loss through the runoff from

Table 18. Average monthly soil loss in the runoff from the experimental plots in 1991 and 1992.

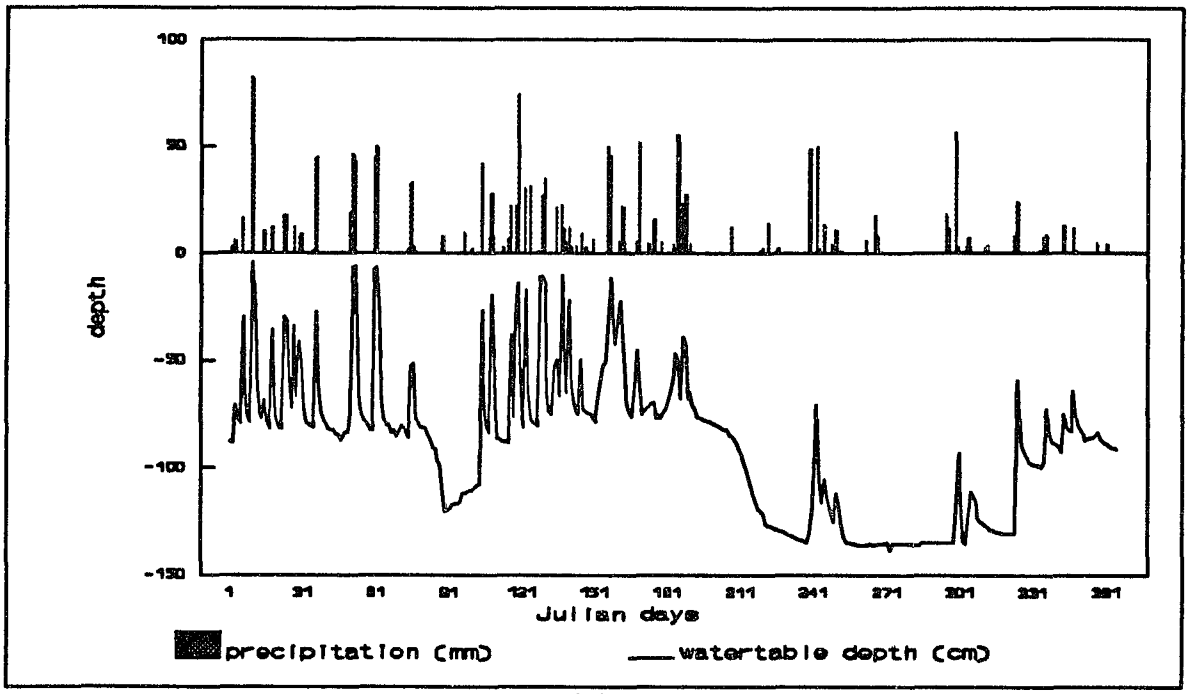
Month/ Year	1991			1992		
	Drained Plots** (kg/ha)	Nondrained Plots* (kg/ha)	% Difference	Drained Plots** (kg/ha)	Nondrained Plots* (kg/ha)	% Difference
January	2911.40	3180.35	8.46	5938.10	7036.06	15.60
February	369.40	773.30	52.23	521.10	821.37	36.56
March	605.27	883.00	31.48	354.71	488.16	27.34
April	1137.13	1108.50	-2.58	9.70	10.59	8.40
May	1129.47	1830.95	38.31	2.15	3.49	38.39
June	1842.87	2915.30	36.79	1693.44	1845.77	8.25
July	1114.16	1838.85	39.41	1052.41	1736.77	39.40
August	120.07	587.65	79.57	1075.57	1901.56	43.44
September	7.60	32.55	76.65	290.82	399.77	27.25
October	33.97	192.00	82.31	24.07	53.10	54.67
November	2.33	16.35	85.75	198.16	291.84	32.10
December	0.70	9.55	92.67	142.30	489.98	70.76
Annual	9274.37	13368.35	30.62	11302.53	15078.51	25.04

** - Average from Plots A, B, and C. * - Average from Plots H and I.

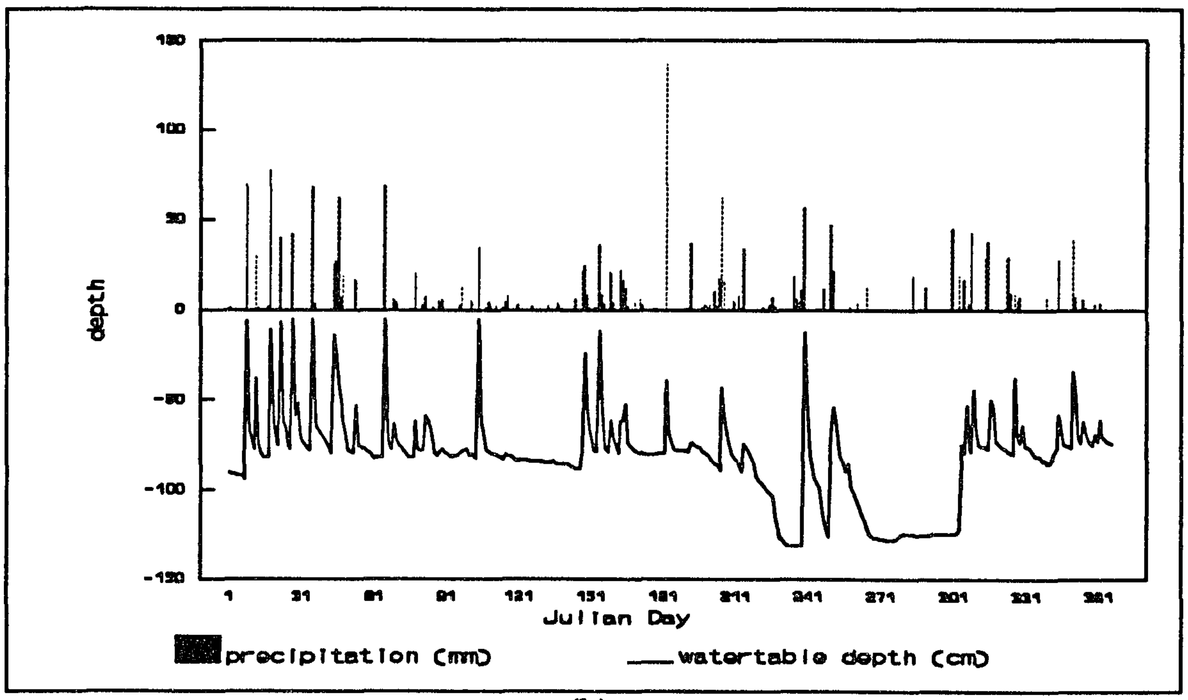
the drained plots were about 31% and 25% less compared to those from the nondrained plots in 1991 and 1992, respectively. About 9,274 kg/ha and 11,163 kg/ha of soil were lost in the surface runoff from the drained plots and about 13,368 kg/ha and 15078 kg/ha from the nondrained plots in 1991 and 1992, respectively. A paired t-test on the average monthly soil losses from the drained and nondrained plots showed a highly significant difference at the 1% level of significance in both years.

4.1.C. Response of the water table

The water table elevations in response to the precipitation and other climatic factors in each of the experimental plots are presented in Figures 12 to 16. As can be noted from the figures, the water table was shallow (less than 100 cm below soil surface) during the months of December to June (1991) and November to June (1992). The large amounts of precipitation in addition to the low evaporative demand during the cool months partly caused and maintained the water table elevations. Transpiration requirement throughout that period was practically nil because the cropping season (for soybeans) in the experimental area was mid-June to late-October. The plowing of the plots during the fall which eliminated most of the post-crop grasses further reduced the transpiration. The presence of approximately 75 cm wide semi-impermeable layer at about 110 cm down the soil profile (see soil profile description, Table 9) aided in the shallow water table formation.

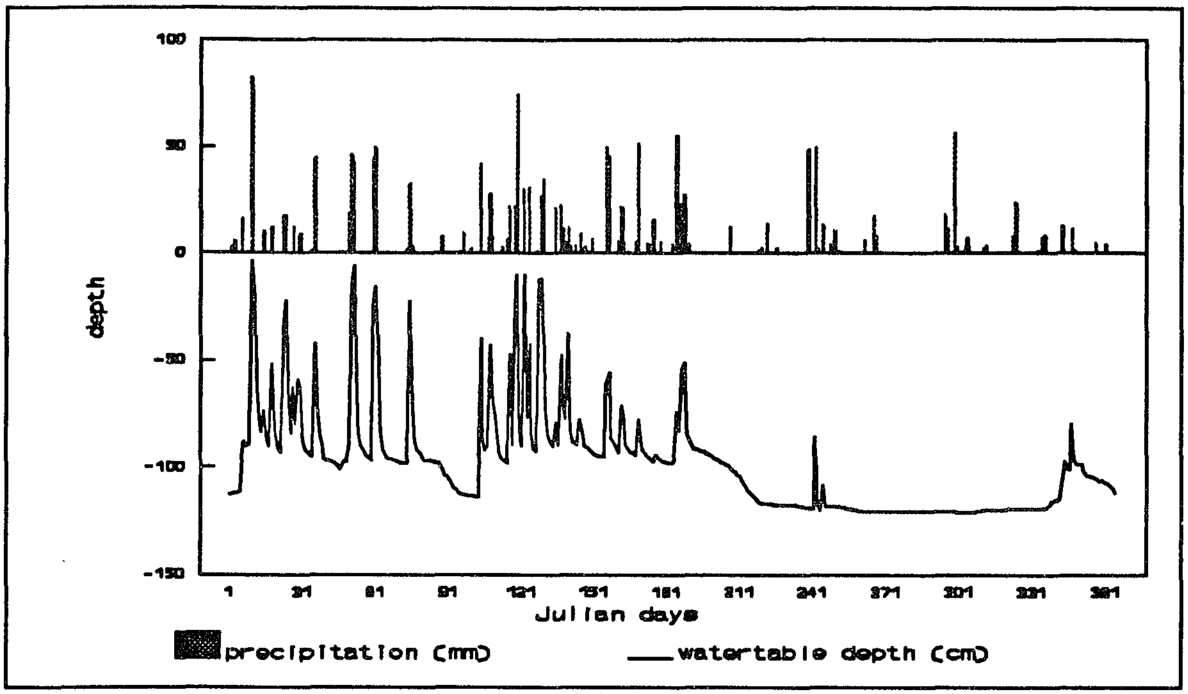


(a)

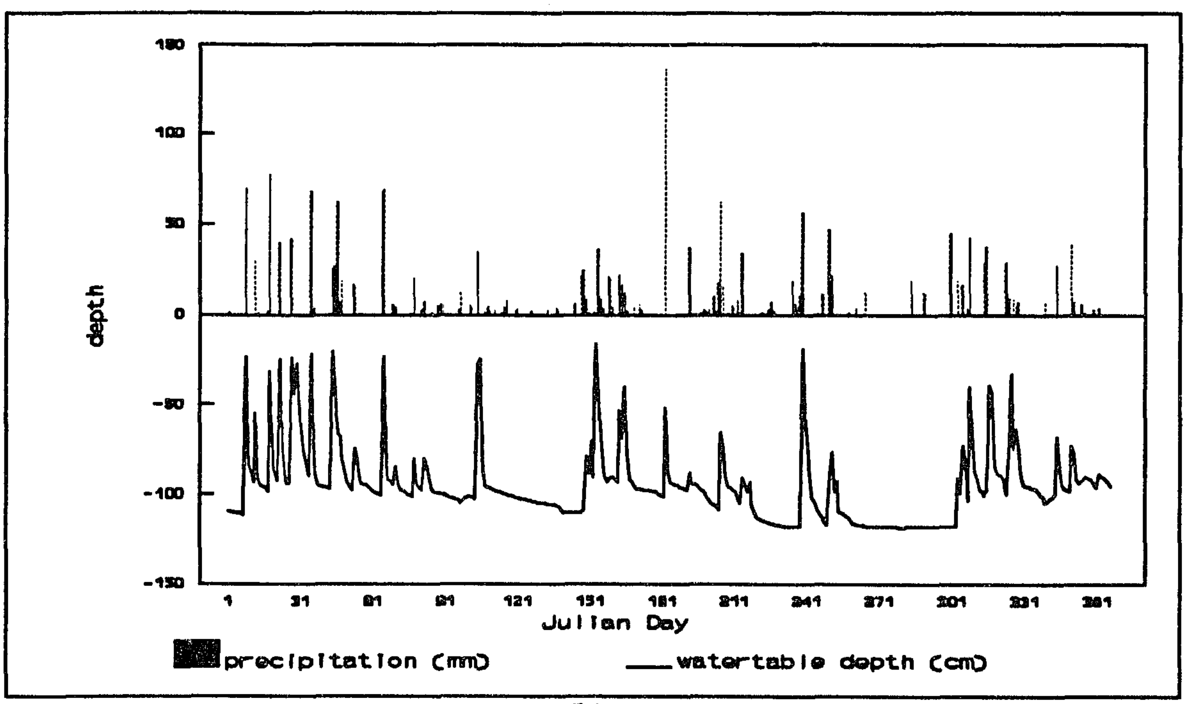


(b)

Figure 12. Observed water table depth and precipitation at plot A in 1991 (a) and 1992 (b).

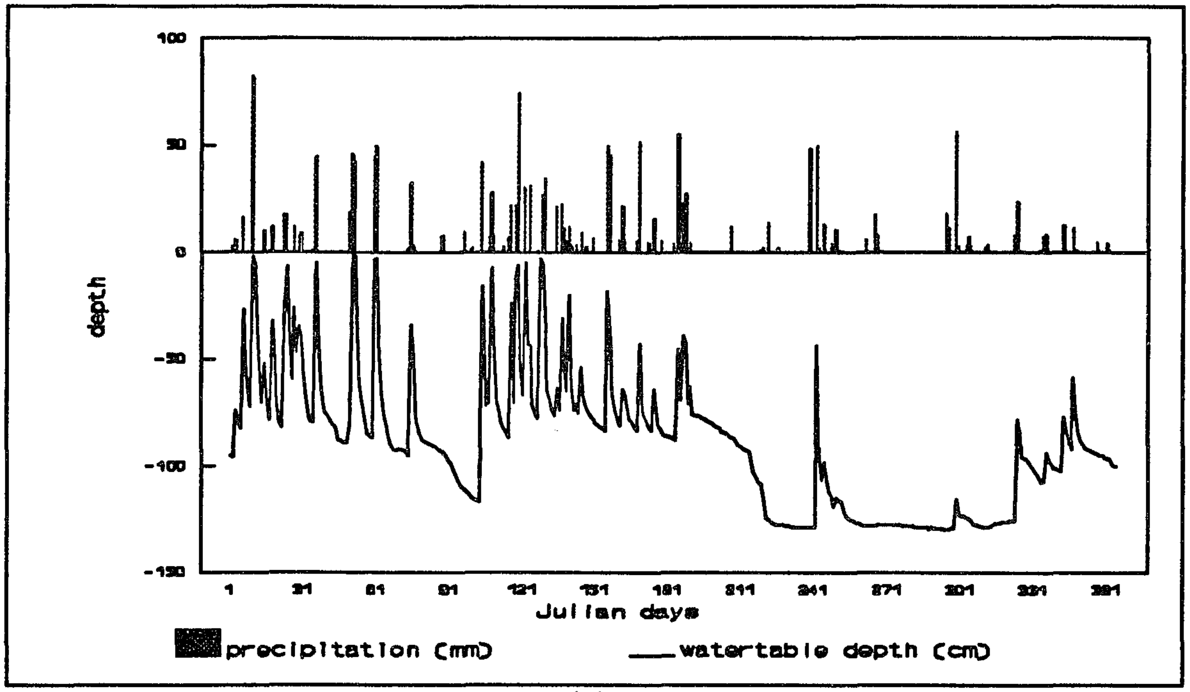


(a)

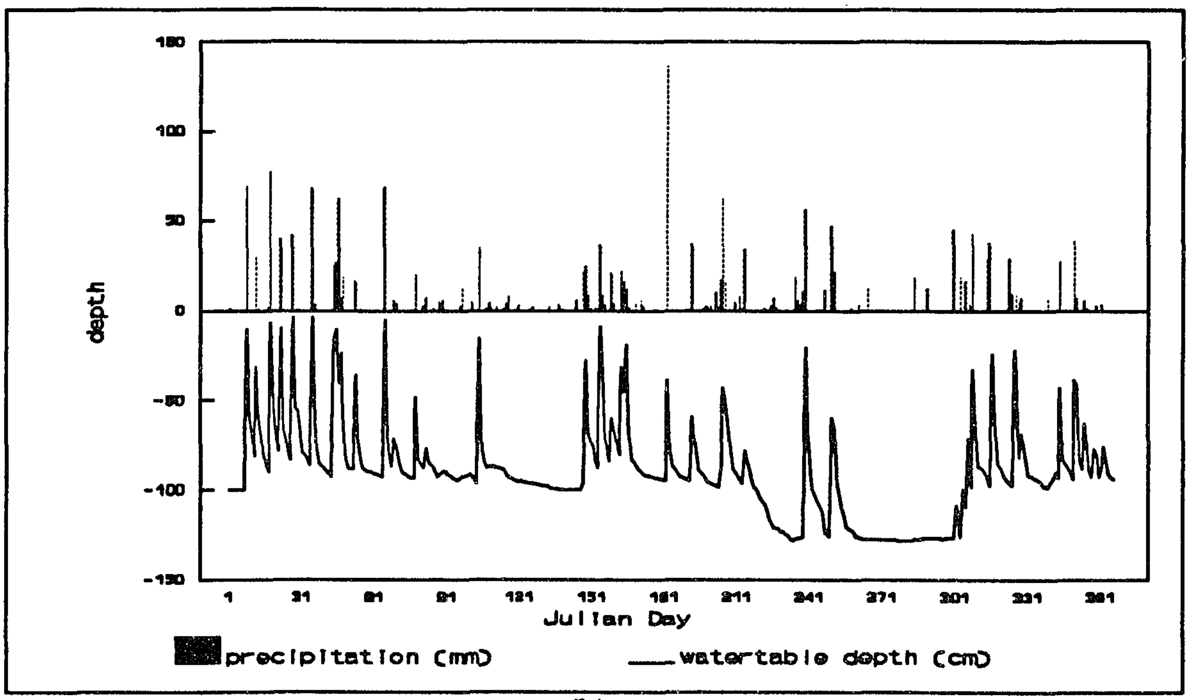


(b)

Figure 13. Observed water table depth and precipitation at plot B in 1991 (a) and 1992 (b).

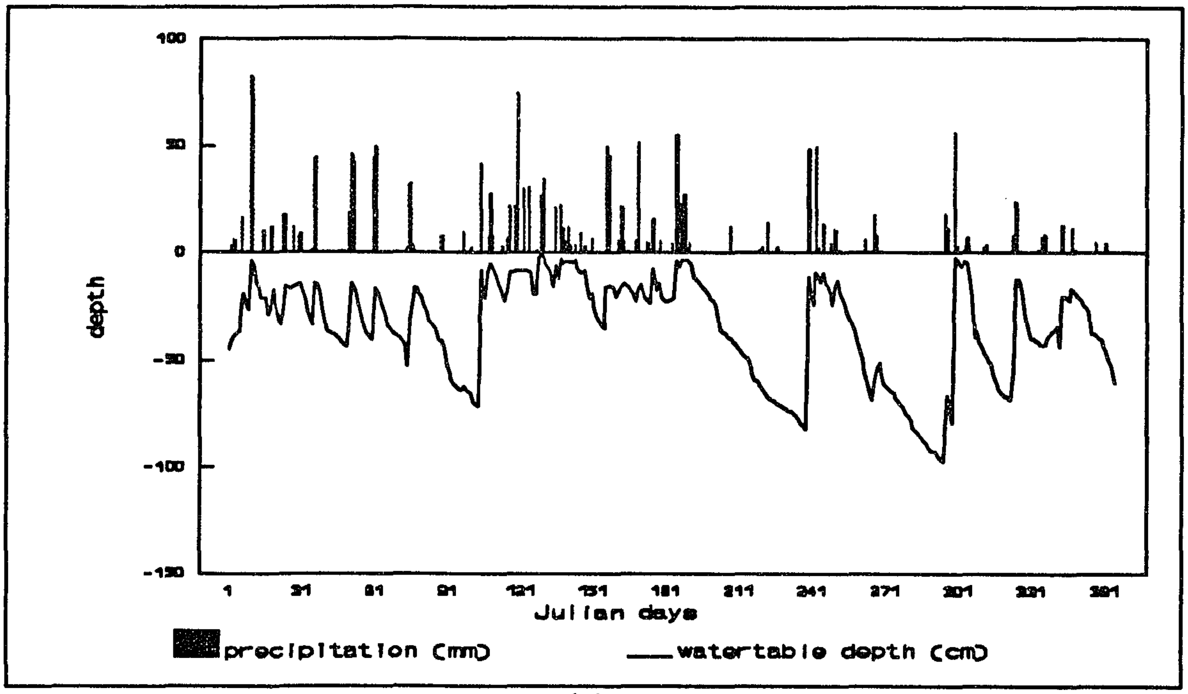


(a)

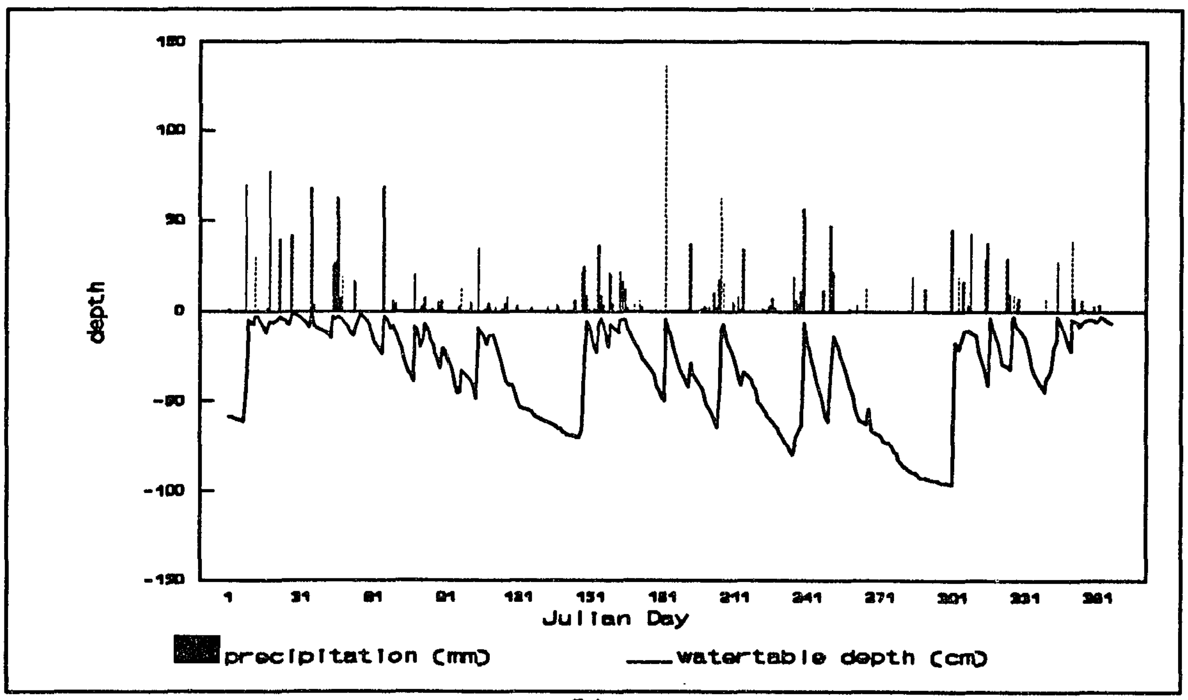


(b)

Figure 14. Observed water table depth and precipitation at plot C in 1991 (a) and 1992 (b).

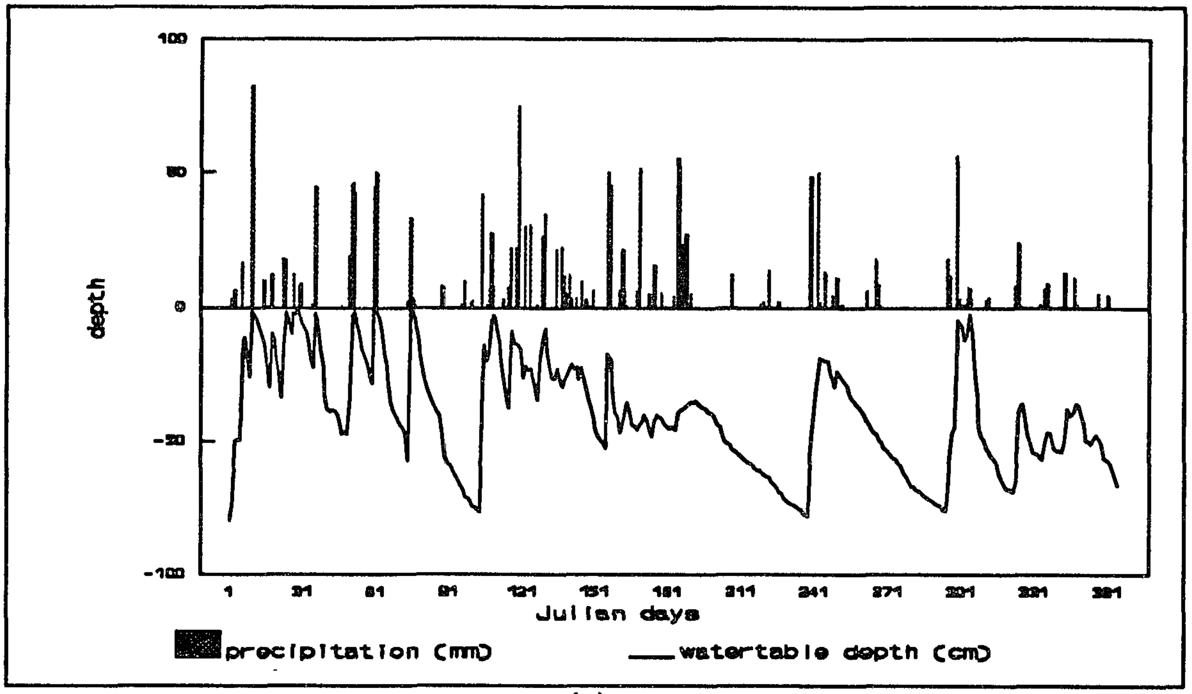


(a)

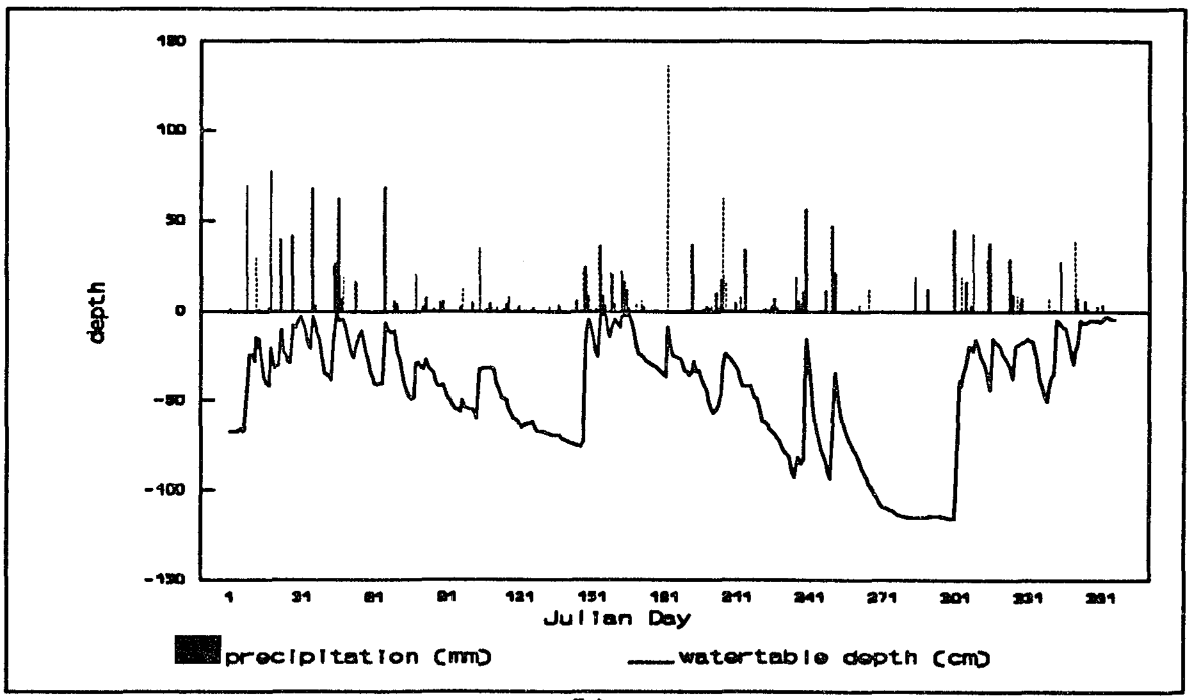


(b)

Figure 15. Observed water table depth and precipitation at plot H in 1991 (a) and 1992 (b).



(a)



(b)

Figure 16. Observed water table depth and precipitation at plot I in 1991 (a) and 1992 (b).

The layer was a physical barrier to the deep percolation or the vertical movement onto the groundwater system.

The movement of water in porous media such as the soil is described by a kinematic, a dynamic, and a thermodynamic relation. Early studies on porous media flow lead to the Navier-Stokes equations which describe the flow of viscous fluids through porous media. These equations, however, are very complicated and difficult to solve even for the simplest boundary conditions, hence, for practical considerations most researchers use the Darcy's law to define and analyze groundwater flow. Although Darcy's law rests only on experimental evidence, it is valid for groundwater flow in any direction in space (Freeze and Cherry, 1979). The Darcy's law states that the flow of water through a porous medium is proportional to the hydraulic gradient (the driving force) and to the property of the conducting medium to transmit the water (hydraulic conductivity). It is used to calculate the total flow of water into and out of an elemental volume which is equal to the total rate of storage which in turn is related to the rate of change in moisture content. The soil moisture content influence the infiltration rate and subsequently the amount of surface runoff.

The impact of the precipitation on the water table was observed to show similar patterns in both the drained and nondrained plots. The higher water table elevations reflect higher amounts of precipitation capable of recharging the groundwater system. A decrease in the water table elevation indicated a more limited amount of precipitation and possibly higher evaporative demand during the period. Comparison among the drained plots showed no significant difference (t-tests (LSD), $\alpha = 0.05$) in the response of the water table among the plots with the same amount of rainfall. The same was observed between the nondrained plots. Hence, Plots A, B, and C and Plots H and I were considered replicates for the drained and nondrained plots, respectively. The variance among the drained plots, however, was significantly different from the variance between the nondrained plots (t-test, $\alpha = 0.05$).

4.1.C.1. Summation of excess water (SEW)

The presence of shallow water table indicates an excess water condition within the upper soil profile. Excess water condition adversely affects crop growth and consequently the potential yield of the crop. This is so because the majority of the crop roots are within the 0 to 60 cm below the soil surface. The excess water in the root zone displaces oxygen and adversely affects the growth and development of plant roots. The adverse effects of a shallow water table, however, vary among crops and soils and with the elevation and duration of the water table during the crop growth stage.

The concept of the summation of excess water (SEW) was originally developed by Sieben (1964) according to Bouwer (1974) and Wesseling (1974). Sieben found that as SEW_{30} values during the growing season increased from 100 to 200 cm-days, the cereal crop yields declined. The SEW_{30} is a measure of the height and duration of a water table within 30 cm of the soil surface.

Based on the Sieben experiment and other subsequent studies, the SEW_{30} had been extensively used to quantify the amount of stress to crops caused by a shallow water table (Carter et al., 1988) with a 200 cm-days threshold. The calculated monthly SEW_{30} values in the drained plots during the soybean growing season (June to October) ranged from 0 to 22.5 cm-days with an average of 13.1 cm-days in 1991 and from 0 to 35.6 cm-days with an average of 40.6 cm-days in 1992. In the nondrained plots, the monthly SEW_{30} values ranged from 0 to 318.1 cm-days with an average of 113.1 cm-days in 1991 and 101.1 cm-days in 1992.

The average annual SEW_{30} of the nondrained plots was 1,921 cm-days, about 6 times higher than that from the drained plots in 1991 (320.59 cm-days). In 1992, the annual average SEW_{30} was 2,370 cm-days and 184.58 cm-days in the nondrained and the drained plots, respectively. These data show that the subsurface drainage effectively reduced the amount of excess water above and near the drains. Presented in Table 19 are the monthly SEW_{30} in the experimental plots in 1991 and 1992. The SEW is a practical and convenient management tool; for example, it can be a significant indicator in the formulation of the planting and harvesting schedules to avoid the detrimental effects of excess water conditions in the root zone. Inspection of the estimated monthly SEW_{30} would indicate the months of June to December as an ideal cropping season as far as excessive water problem is concerned. The SEW_{30} threshold of 200 cm-days, however, should be applied only to the length of the crop growing period and not on annual basis as a field crop seldom stays longer than six months in the field. The SEW can also be used to assess the quality of drainage which is of interest in drainage design. It can be used as an indicator of the volume of water that needs to be drained during a certain period.

The calculation of the SEW was extended to include 45 cm and 60 cm water table depths for a better understanding and comparative assessment of the behavior of the water table in both the drained and nondrained plots. Tables B.1 and B.2 in Appendix B present the calculated SEW_{45} and SEW_{60}, respectively. The calculated annual average SEW_{45} in the drained plots were 679 cm-days and 428 cm-days in 1991 and 1992, respectively, while that of the nondrained plots were 4,500 cm-days and 5,019 cm-days, respectively. The calculated annual average SEW_{60} were 1,197 and 834 cm-days in the drained plots for 1991 and 1992, respectively, while in the nondrained plots the calculation yield 8,044 cm-days and 8,359 cm-days for 1991 and 1992, respectively. The SEW_{60} obviously was higher than the SEW_{45} and SEW_{30} and SEW_{45} was higher than SEW_{30}.

4.2. Field tracer experiment

A total of 455 samples were collected in the field tracer experiment which lasted 608 days from the tracer application (March 1991) until after the harvesting of the 1992 soybean crop (November 1992). There were 210 samples from the 1 m monitoring wells with 113 samples from the drained

Table 19. Monthly SEW_{30} (cm-days) in the experimental plots in 1991 and 1992.

Monthh	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
						1 9 9 1							
Plot A	55.66	30.98	47.12	35.44	74.32	22.50	2.99	0.00	0.00	0.00	0.00	0.00	269.01
Plot B	63.44	42.34	22.31	25.58	76.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	230.12
Plot C	97.84	102.0	55.58	79.52	112.03	7.22	6.86	1.63	0.00	0.00	0.00	0.00	462.65
Avg-Dr	**72.31**	**58.44**	**41.67**	**35.95**	**87.60**	**9.91**	**3.26**	**0.54**	**0.00**	**0.00**	**0.00**	**0.00**	**320.59**
Plot H	286.57	117.79	120.43	257.36	646.23	312.15	318.06	62.28	124.79	127.66	86.67	106.17	2470.16
Plot I	429.65	161.99	218.55	164.60	182.34	19.28	0.00	0.81	51.95	113.58	29.53	0.00	1372.28
Avg-Ndr	**358.11**	**139.89**	**169.49**	**210.98**	**414.28**	**165.72**	**159.03**	**31.54**	**88.37**	**120.62**	**58.10**	**53.08**	**1921.22**
						1 9 9 2							
Plot A	85.82	65.68	29.33	9.19	0.90	20.14	0.00	19.98	0.00	0.00	6.79	1.50	239.93
Plot B	14.14	17.90	6.16	0.30	0.00	12.60	0.00	11.32	0.00	0.00	0.68	0.00	63.10
Plot C	86.08	62.85	23.09	4.25	0.47	35.56	2.58	18.94	0.64	0.00	11.73	4.51	250.70
Avg-Dr	**62.01**	**48.81**	**19.53**	**4.58**	**0.46**	**22.77**	**0.86**	**16.75**	**0.21**	**0.00**	**6.40**	**2.00**	**184.58**
Plot H	580.99	560.31	336.11	121.23	63.62	331.89	94.62	43.97	35.79	25.15	198.94	516.62	2909.24
Plot I	192.73	378.67	120.33	1.34	71.55	403.36	42.66	32.55	.000	0.64	105.14	482.28	1831.25
Avg-Ndr	**386.86**	**469.49**	**228.22**	**61.28**	**67.58**	**367.62**	**68.64**	**38.26**	**17.90**	**12.90**	**152.04**	**499.45**	**2370.24**

plots and 97 samples from the nondrained plots. From the 2 m monitoring wells, a total of 245 samples were collected, 147 and 98 samples from the drained and nondrained plots, respectively. The difference in the number of samples between the 1 m and the 2 m depths was due to the water table levels. During periods of low or no precipitation, the water table depths were below one meter from the soil surface. Hence, no samples were available for collection in the 1 m monitoring wells especially in the drained plots.

The tracer Br, from KBr, was expected to dissolve readily into the soil solution since it is a highly soluble chemical. Further, it was expected to be moved into the lower soil horizons as the precipitation percolated into the soil profile. Seven days after the tracer application, an intermittent precipitation occurred. The precipitation, which lasted for four days, totaled 40.6 mm. Percolation increased the water table levels in all the experimental plots. The first water samples were collected on Julian day 77, 10 days after the application (daa) of the tracer. The highest Br concentration detected by ion chromatography from these first water samples came from the 1 m sample of Plot H which yielded a concentration of 1,448 mg/L. The concentrations from the other plots ranged from 205 mg/L (Plot B) to 664 mg/L (Plot I) for the 1 m depth and 8 ppm (Plot B) to 118 mg/L (Plot I) for the 2 m depth. The observed bromide concentrations are listed in Appendix C. The immediate response of the water table to the tracer confirms the high solubility of the chemical. The high concentrations observed, however, were probably influenced by preferential or macropore (Everts and Kanwar, 1990) or bypass flow (Sharma and Hughes, 1985; Biggar and Nielsen, 1976). Previous research has shown that solutes often travel faster than indicated by the theoretical solute front because of limited mixing with a large fraction of soil water through bypass flow (Jaynes et al.,1988; White, 1984). The application sites of the tracer were untilled, hence, the existing macropores probably were left intact. It was not necessary for pores responsible for preferential flow activity to extend to the soil surface to actively conduct water and solutes deeper into the soil (Hammermeister et al., 1982; Thomas and Phillips, 1979). Research on the abundance and extent of macropores in untilled areas was not covered in this study.

The subsequent samples from the monitoring wells showed the Br concentrations were actively fluctuating until 317 daa. For example, five concentration peaks in excess of 1000 mg/L were observed in the 1 m depth samples from the drained plots reaching an average maximum concentration of 4,580 mg/L 69 days after the tracer application. Samples from the nondrained plots (1 m depth) showed nine concentration peaks yielding a maximum of 9,726 mg/L 38 days after the Br application. Summarized in Appendix D were the averaged observed bromide concentrations in the drained and nondrained plots and the cumulative three-days rainfall before the sample collection during the whole study period.

Figures 17 and 18 shows the averaged observed bromide concentrations in the drained and nondrained plots at 1 m and 2 m depths, respectively. The average Br concentrations from the 1 m depth were substantially higher than those from the 2 m depths from both the drained plots and nondrained plots through the duration of the experiment. The observation indicates that chemical concentration varies with the water table depth, with the higher concentrations in the water table closest to the soil surface. This suggests that water soluble chemicals do not migrate deep into the aquifer but stay near the surface of the water table. The average Br concentrations from the drained plots on 608 daa (last sampling date) were found to be 112 mg/L and 65 mg/L from the 1 m and 2 m depths, respectively, while those from the nondrained plots were 153 mg/L and 34 mg/L from the 1 m and 2 m depths, respectively. The continued detection of Br even after 608 daa in the water table in both drained and nondrained plots, albeit in low concentration, indicates some residence time for the tracer. Other chemicals that behave similarly to Br like NO_3^- and others, probably exist in the water table. Incidentally, the analysis of the samples from both the surface runoff and the subsurface outflow yield no detectable amount of the Br tracer. The amount of Br from these samples was probably too diluted to be detected as the tracer was applied around each of the monitoring wells located near the center of the plots (see plot layout, Figure 11). Shown in Figures 19 and 20 are the averaged observed bromide concentration from the drained and nondrained

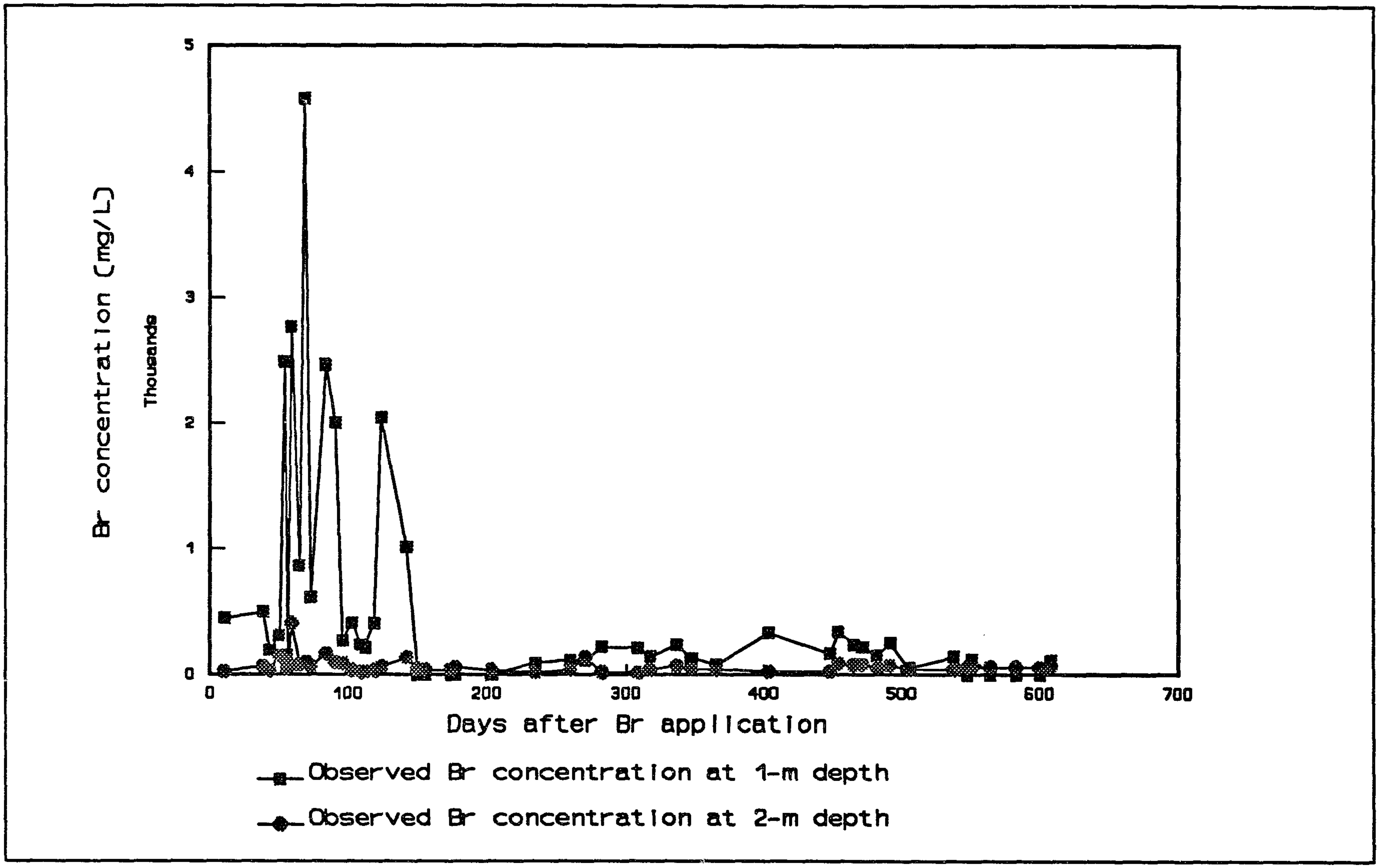


Figure 17. Averaged observed bromide concentration in the drained plots at 1 m and 2 m depths.

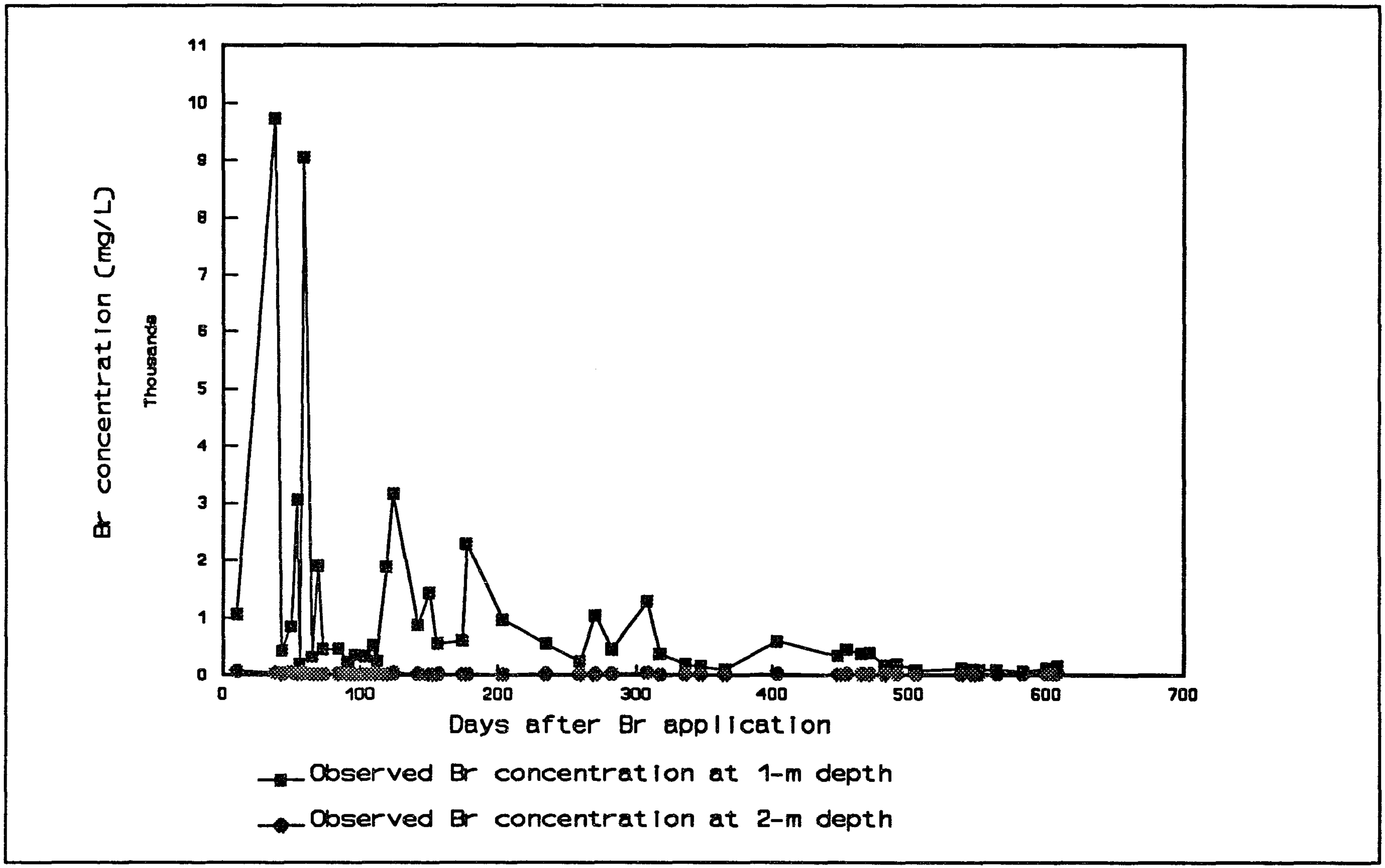


Figure 18. Averaged observed bromide concentration in the nondrained plots at 1 m and 2 m depths.

plots at 1 m depth and 2 m depths, respectively. As can be noted from Figure 19, the average concentrations in the drained plots were significantly lower (t tests, $p < 0.05$) than those from the nondrained plots at the 1 m depth during the duration of the study. This indicates the influence of the drainage system in the redistribution of the tracer. The tracer was assumed to be contained in the soil solution and the reduction of the soil moisture above and near the drains presumably reduced the amount of the tracer in the solution. In contrast, the average concentrations of the tracer from the drained plots at 2 m depth were significantly higher (t tests, $p < 0.05$) than those from the nondrained plots (Figure 20). This indicates that the plots installed with subsurface drainage may have a higher potential risks of contaminating the lower soil profile and eventually the groundwater as compared to the nondrained plots especially with a highly persistent chemical of high leaching potential. Linear regression between the drained and nondrained plots (both at 1 m and 2 m depths), however, did not show a significant fit with $R = 0.17$ and 0.03, respectively. During periods when the water table depths at the drained plots were below one meter, i.e., between 150 and 203 daa (Figures 12(a) to 14(a) and Appendix D, Julian days 217-269), 547 daa (Figures 12(b) to 14(b) and Appendix D, Julian day 248), and 564 to 600 daa (Figures 12(b) to 14(b) and Appendix D, Julian days 266 to 302), no samples were collected in the drained plots and those dates were excluded in the analysis.

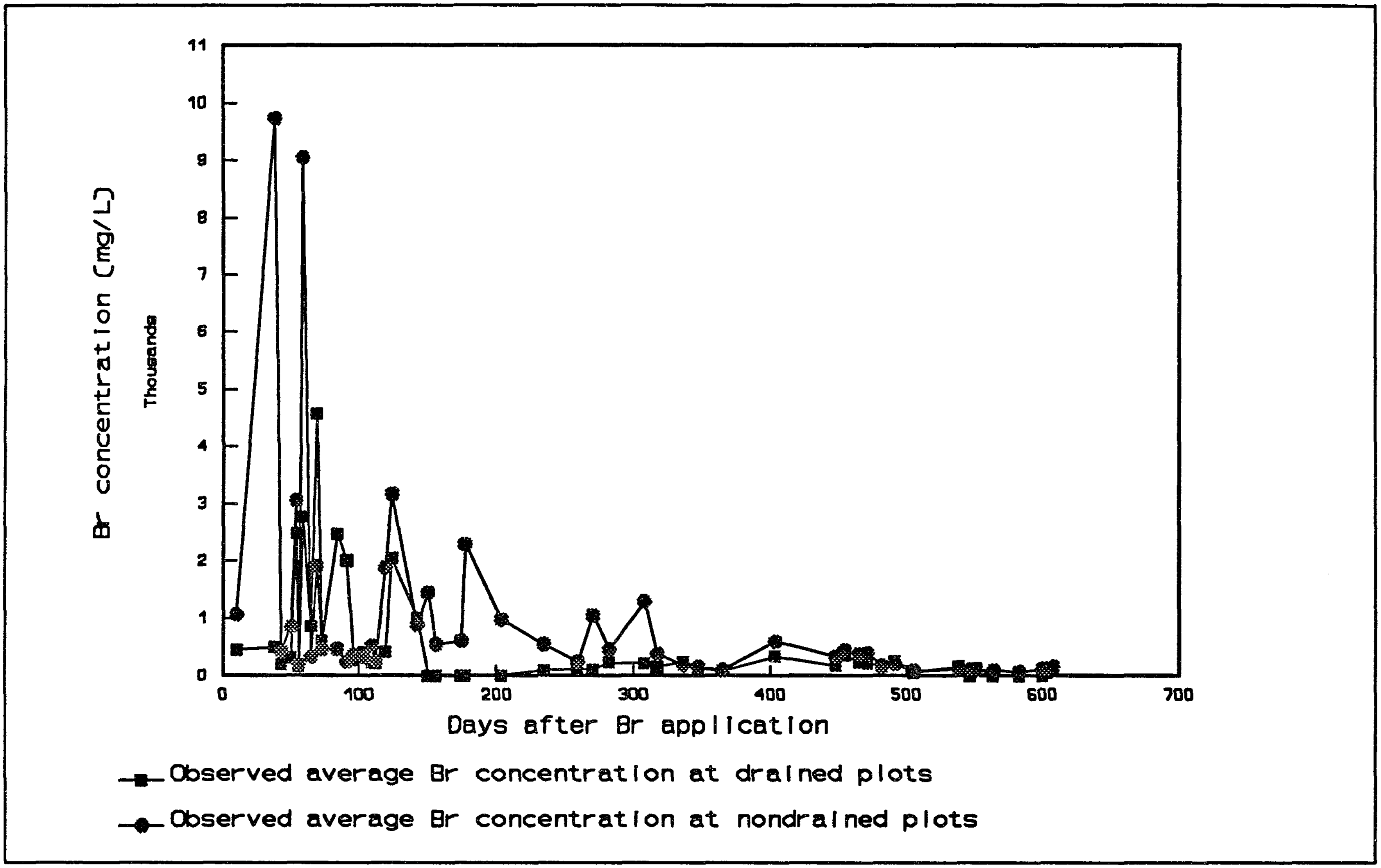


Figure 19. Averaged observed bromide concentration at 1 m depth from the drained and nondrained plots.

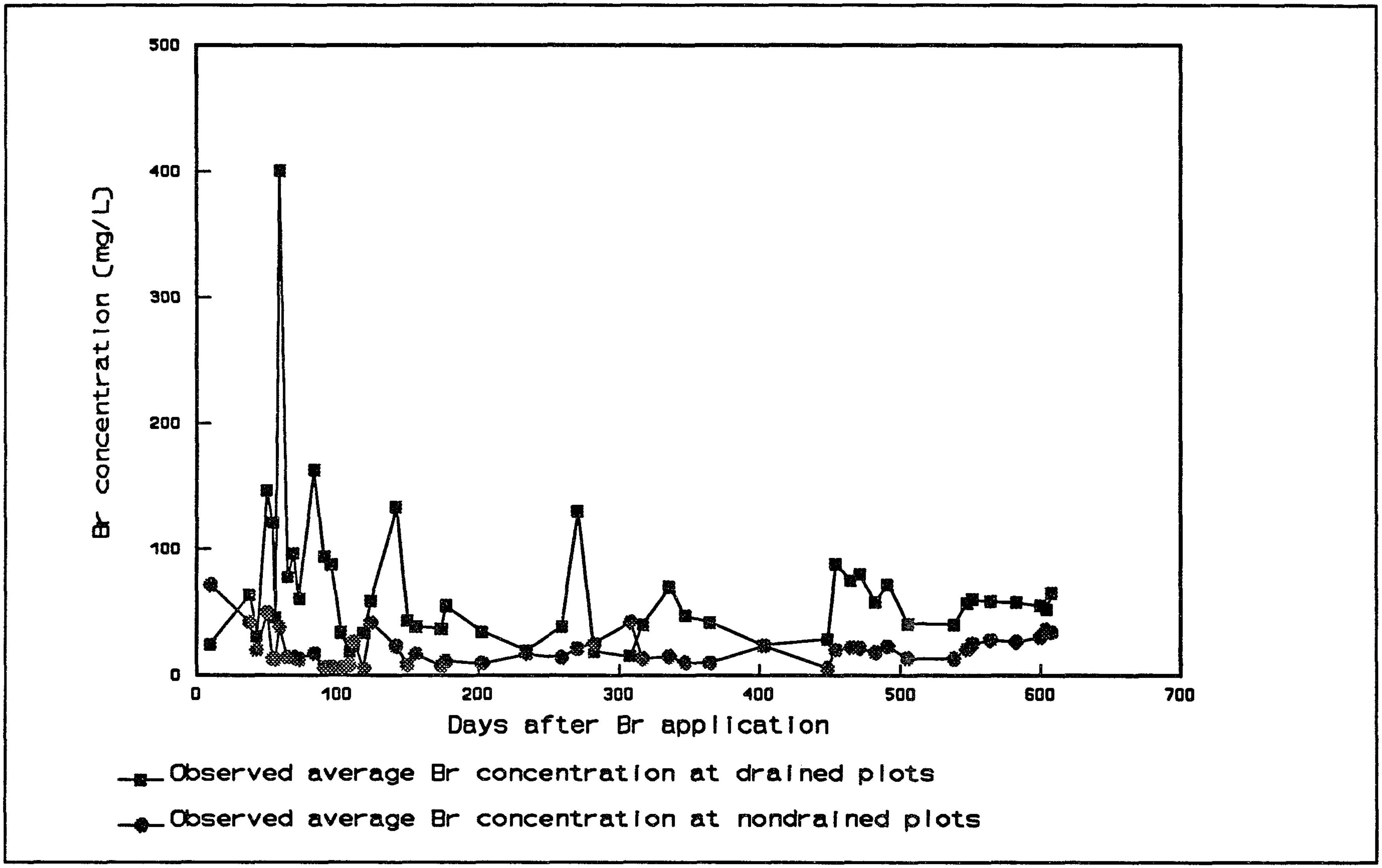


Figure 20. Averaged observed bromide concentration at 2 m depth from the drained and nondrained plots.

The internal drainage of the soil, which was primarily due to the lateral and vertical water movements in the soil profile, continuously reduced the amount of tracer in the water table. Soluble materials like the tracer usually move with the water flow. In addition, during periods of very low or no precipitation, the evapotranspiration requirement is supplied by the upward movement of water from the wetter zones near the water table towards the drier zones near the soil surface. This upward water movement increased the water table depth and decreased the tracer concentration in the water table. After each rain, however, the tracer concentrations from the monitoring wells were observed to increase compared with the concentrations before the rain. It is theorized that as the moisture from the water table (upward flux) containing the dissolved tracer evaporates in the upper layers of the soil profile or absorbed by plant roots, the tracer probably precipitates (due to lack of moisture) or stays trapped with the thin film of soil water (called hygroscopic water) found around each soil particle. And with the incoming water (percolation) from rain, the tracer will again be dissolved into the soil solution resulting to increased concentration in the water table. The process is repeated whenever rain occurs, thus, tracer concentrations varies as the water table level changes after each rain occurrence. There were no measurements made of the amount and rate of infiltration after each rain. To this extent no comparison was made relevant to its efficiency in moving the tracer in the soil profile. The only openings in the monitoring tube (where water can enter) were at the lower end of the tube (at 1 m and 2 m, respectively) thus the presence of the tracer in the tube would suggest that the percolating water had moved the tracer that distance.

Separate regression-correlation analyses performed for the drained and nondrained plots showed no satisfactory fit between the water table depth and the observed tracer concentration in the water table samples. This does not mean, however, that no relationship exists between the water table depth and the risk of pollution of the groundwater system. The risk of pollution is influenced by several factors (as discussed earlier) and the depth of the water table is not one of the most critical factors. The observation merely showed that the water table depth is not a good predictor for the change in the chemical concentration in the aquifer. The same observations were noted with the tracer concentration data regressed against the days after application. The tracer Br is an inert compound and does not easily undergo chemical degradation.

4.3. Herbicide monitoring study

Three herbicides, Trifluralin, Metolachlor, and Metribuzin, were monitored in the study. The monitoring experiment covered two soybeans cropping seasons labeled 1991 and 1992 cropping seasons, respectively. These herbicides were applied pre-emergent, that is, before the planting of the soybean crop. Samples from the drainage discharge (runoff and subsurface) were used to quantify losses from the plots while samples from the soil and the monitoring wells were used to quantify their persistence and leaching property. Data analysis for each of these herbicides were done separately to evaluate their fate and movement in the field.

4.3.A. Trifluralin

Trifluralin {2, 6 dinitro-N, N-dipropyl-4-(trifluoromethyl) benzenamine} is a pre-emergent herbicide listed to control a wide variety of grasses and broad leaf weeds. It is widely used in several crops including wheat, barley, cotton, and soybeans, among others. A detailed documentation of this herbicide is available in the Herbicide Handbook (1989).

Summarized in Table 20 are the observed average concentrations of Trifluralin in the runoff (combined water and sediments) from the drained and nondrained plots in 1991 and 1992 cropping seasons. During the 1991 cropping season, the peak average concentration observed from the drained plots was 0.90 µg/L (13 daa) while it was 0.32 µg/L (6 daa) from the nondrained plot. During the 1992 cropping season, the peak average concentration was 0.24 µg/L (29 daa) and 0.44 µg/L (29 daa) from the drained and nondrained plots, respectively. The variance in the observed peak concentrations was largely due to the time of runoff occurrence after the herbicide application. The time of runoff occurrence dictates the concentration of soil-adsorbed chemical available for transport. Chemical decay (usually referred to as half-life) reduces the concentration of chemicals present in the soil. The longer the chemical stays in the soil before runoff occurs, the lower

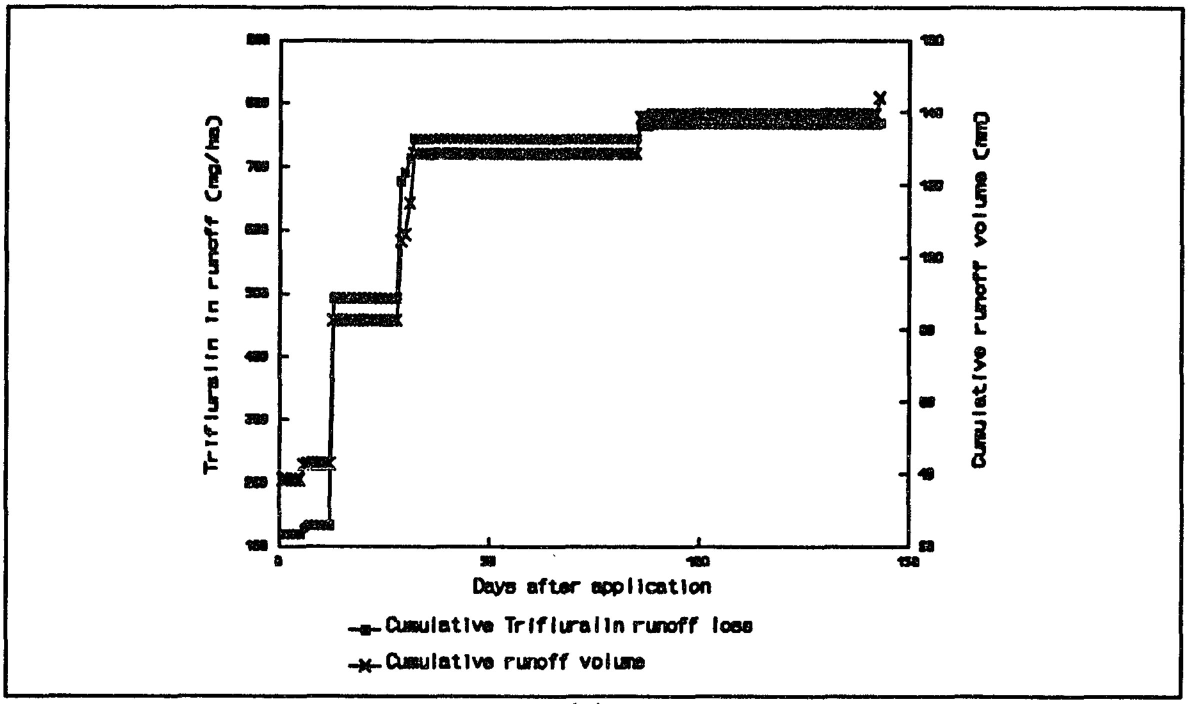
Table 20. Observed average Trifluralin concentration in the runoff from the drained and nondrained plots after the application of 1683 g/ha in 1991 and 1992 cropping seasons.

1991 Cropping Season				1992 Cropping Season			
Drained Plots*		Nondrained Plot		Drained Plots**		Nondrained Plot	
DAA (Jun 5)	Concentration (μg/L) [s.d.]	DAA (Jun 30)	Concentration (μg/L)	DAA (Jun 16)	Concentration (μg/L) [s.d.]	DAA (May 1)	Concentration (μg/L)
1	0.31 [0.06]	5	0.28	15	0.18 [0.08]	33	0.26
6	0.27 [0.01]	6	0.32	29	0.24 [0.08]	34	0.24
7	0.84 [0.99]	7	0.27	39	0.16 [0.01]	39	0.28
13	0.90 [0.85]	9	0.26	48	0.00 [ltd]	48	0.16
29	0.85 [0.40]	58	0.23	85	0.15 [0.15]	61	0.18
30	0.66 [0.57]	61	0.22	135	0.17 [0.10]	75	0.22
31	0.27 [0.48]	63	0.21	139	0.24 [0.06]	82	0.44
32	0.22 [0.41]	68	0.21	-	-	85	0.16
34	0.19 [0.14]	84	0.20	-	-	94	0.13
86	0.21 [0.04]	85	0.20	-	-	131	0.16
143	0.06 [0.05]	115	0.18	-	-	-	-

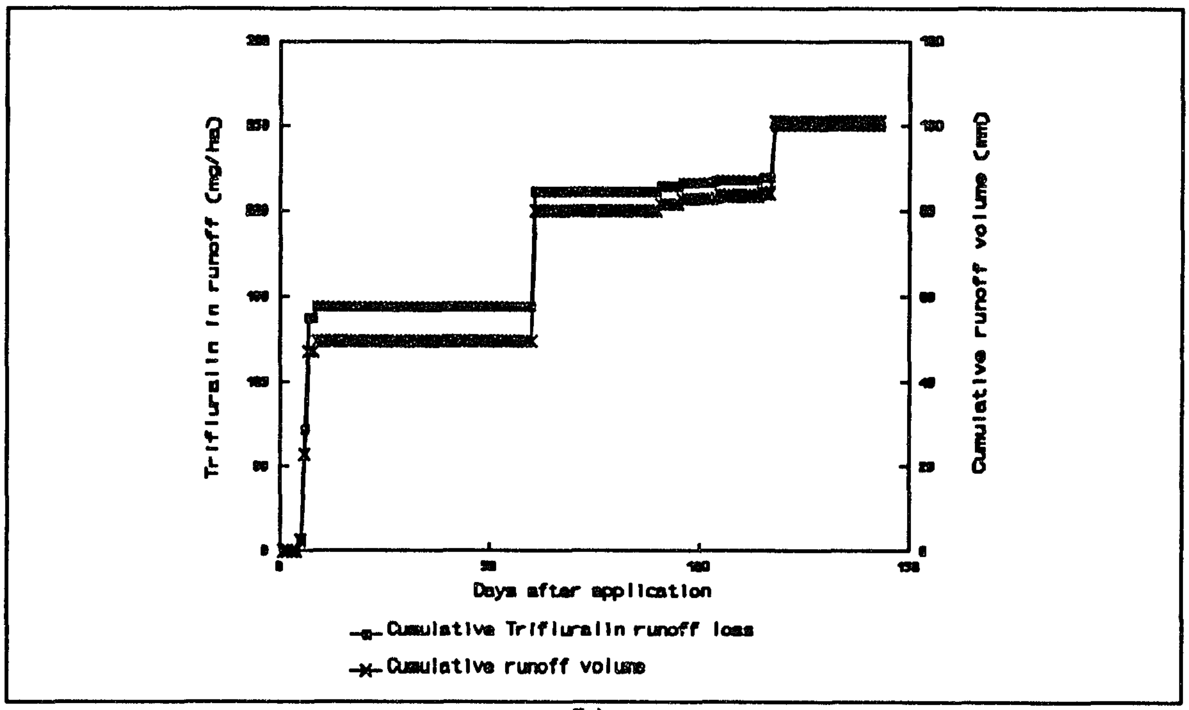
* - average of plots A, B, C. ** - average of plots B and C. ltd - less than the detection limit

the concentration of the chemical will be. On the other hand, the volume and the rate of surface runoff determine the amount of sediments in the runoff which, in turn, is responsible for the total amount of chemical lost.

Shown in Figures 21 and 22 are the data of the cumulative Trifluralin loss in the runoff from the drained and nondrained plots in 1991 and 1992 cropping seasons. The runoff losses were plotted against the days after the herbicide application. The chemical load in the runoff were computed per storm event from the first runoff after the herbicide application until the last runoff event during the season and summed to represent the total amount herbicide loss in the runoff for the season. During the 1991 cropping season, about 768 mg/ha (0.046 per cent of the applied herbicide) was lost in the runoff from the drained plots. The analysis involved 12 runoff-producing storm events out of 42 storm events in the year. From the nondrained plots, about 250 mg/ha of Trifluralin was lost from 11 storm events during the cropping season. The amount of Trifluralin loss from the drained plots was larger than the amount lost from the nondrained plot during the 1991 season. The difference in the runoff losses between the drained and nondrained plots was due to the amount of rain and the consequent runoff which occurred during the interval between the herbicide applications. The total average runoff volume from the drained plots was 144.2 mm while that of the nondrained plot had 100.8 mm. The herbicide was applied on June 5 in the drained plots while the nondrained plots were applied 25 days later (June 30).

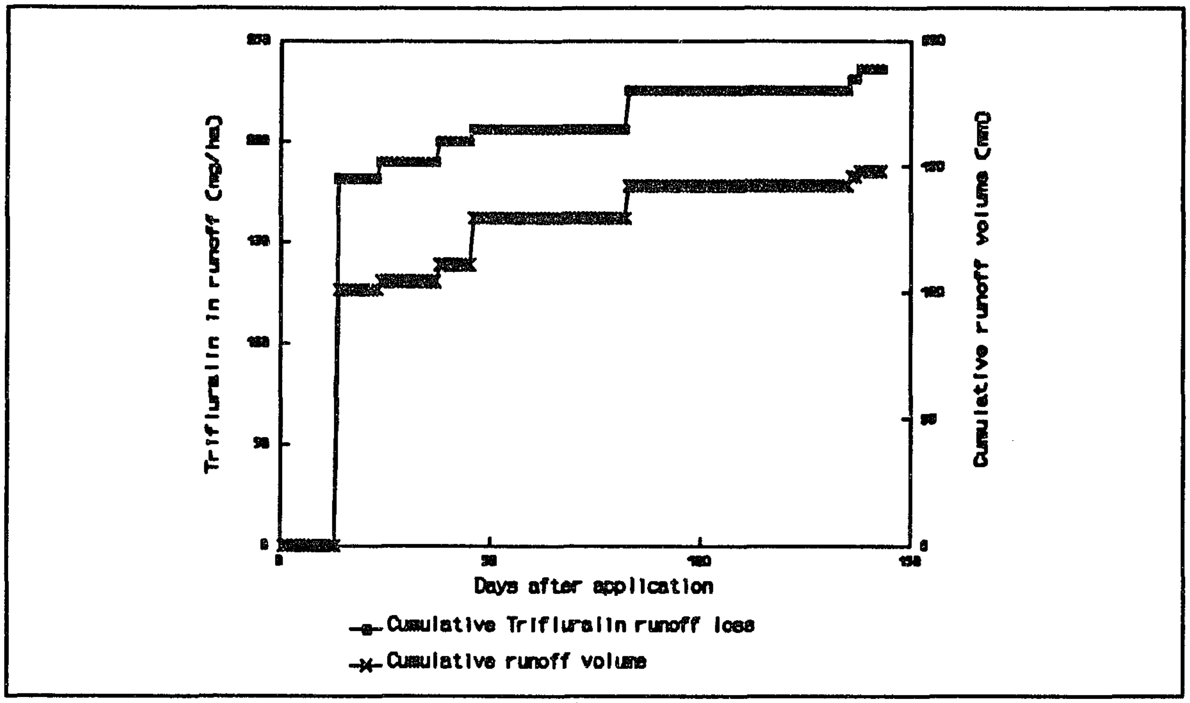


(a)

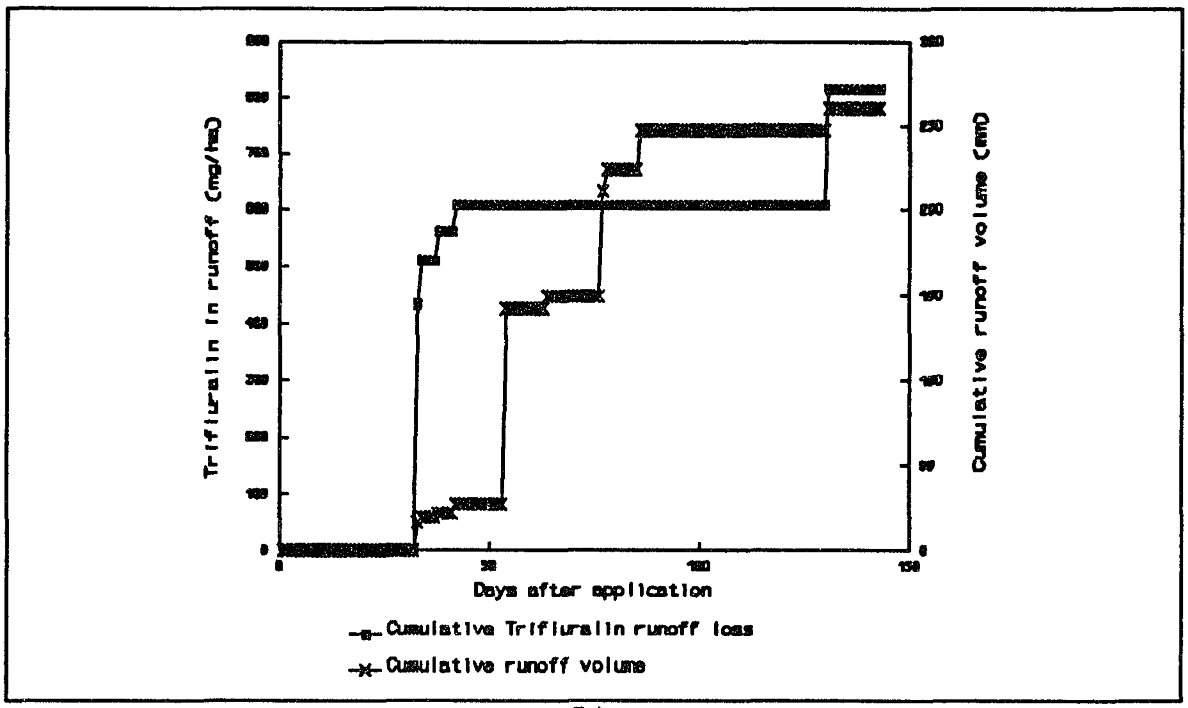


(b)

Figure 21. Cumulative Trifluralin loss in the surface runoff from the drained (a) and nondrained plots (b) during the 1991 cropping season.



(a)



(b)

Figure 22. Cumulative Trifluralin loss in the surface runoff from the drained (a) and nondrained plots during the 1992 cropping season.

A total of 215.4 mm of precipitation had fallen during the 25-days interval and produced 82.8 mm of surface runoff. The difference in cumulative rainfall during the period translated into a great difference in the amount of runoff for the two plots. The surface runoff during the interval was responsible for 64% loss of the applied herbicide in the drained plots. In addition, larger surface runoffs occurred immediately after the herbicide application in the drained plots. For example, an average 38.1 mm runoff which occurred the day following the herbicide application in the drained plots was responsible for 15% of the total herbicide loss for the season. On the other hand, runoff in the nondrained plots did not occur until five days after the application and the runoff was only 2.5 mm which accounted for about 3% of the of the total herbicide loss during the season.

During the 1992 cropping season, the herbicide was applied on May 1 in the nondrained plot and on June 16 (47 days later) in the drained plots. During the 47 days period between the herbicide applications, a total of 144 mm of rain fell which yielded 39.3 mm of surface runoff in the nondrained plot. The total runoff loss from the nondrained plot was 815 mg/ha. The runoff loss in the nondrained plot during the 47 days interval yielded 60.84 mg/ha. The averaged total Trifluralin runoff loss from the drained plots was 236 mg/ha which was 71% of the total runoff loss from the nondrained plot. The variance in the total runoff losses observed from the drained and nondrained plots in both seasons emphasized the important role of the time of runoff occurrence following the time of chemical application in the amount of chemical lost in the surface runoff.

Presented in Table 21 are the average concentrations and cumulative loss of Trifluralin in the subsurface outflow in 1991 and 1992 cropping seasons. The average concentrations range from 0.15 µg/L to 0.25 µg/L in the 1991 cropping season while the range was from 0.08 µg/L to 0.14 µg/L in 1992. The observed concentrations of Trifluralin from the subsurface drainage were substantially lower compared to the concentrations recovered from the runoff. The peak concentration from the subsurface outflow was only about 28% of the peak concentration observed from the runoff in 1991 while it was 58% in the 1992 cropping season. This is an indication of low leaching potential characteristic for Trifluralin. The total Trifluralin loss in the percolate water were also much lower compared to the total loss from surface runoff. The total Trifluralin loss in the subsurface outflow in 1991 cropping season was 146.16 mg/ha; in the 1992 cropping season, it was 73.30 mg/ha.

The average Trifluralin concentration in the soil (0-15 cm) from the drained and the nondrained plots are listed in Table 22 for 1991 and 1992 cropping seasons. Based from these concentrations the half-life (time that the chemical losses half of its original concentration through degradation) of Trifluralin in the soil was estimated using the equation:

$$HL = t_{1/2} = \frac{-0.693t}{\ln(Xt/Xo)} \qquad (5)$$

Table 21. Average concentration and cumulative loss of Trifluralin in the subsurface outflow in 1991 and 1992 cropping seasons.

1991 Cropping Season				
DAA	Outflow* (mm)	Concentration (µg/L) [s.d.]	Load (mg/ha)	Cum. Loss (mg/ha)
1-3	1.24	0.16 (0.03)	19.84	19.84
4-15	1.76	0.25 (0.01)	44.00	63.84
16-27	0.37	0.22 (0.04)	8.14	71.98
28-38	2.92	0.23 (0.01)	67.16	139.14
39-50	0.16	0.24 (0.02)	3.84	142.98
51-63	0.01	0.18 (0.03)	0.18	142.98
90-101	0.18	0.15 (0.03)	3.00	145.98
1992 Cropping season				
1-2	1.03	0.08 (0.01)	21.03	21.03
3-13	0.06	0.13 (0.06)	1.87	22.90
14-25	0.61	0.12 (0.04)	18.65	41.55
26-38	0.10	0.08 (0.02)	2.07	43.62
39-48	0.51	0.14 (0.03)	18.13	61.75
49-72	0.02	0.09 (0.07)	0.14	61.89
73-85	0.32	0.14 (0.01)	11.41	73.30

* - average of plots A, B, and C.

Table 22. Average Trifluralin concentration in the soil (0-15 cm) after application of 1683 kg/ha in 1991 and 1992 cropping seasons.

1991 Cropping season			
Drained Plots*		Nondrained Plot	
DAA (June 5)	Concentration (ng/g) [s.d.]	DAA (June 30)	Concentration (ng/g)
7	115.75 (30.40)	5	113.86
14	106.68 (10.98)	10	98.07
20	106.79 (9.43)	18	93.02
31	107.42 (10.74)	27	97.10
36	86.55 (14.66)	60	47.78
63	60.66 (3.55)	ns	-
1992 Cropping season			
Drained Plots**		Nondrained Plot	
DAA (June 16)	Concentration (ng/g) [s.d.]	DAA (May 1)	Concentration (ng/g)
2	98.92 (4.61)	3	35.97
10	35.00 (3.54)	7	22.20
21	24.88 (5.83)	18	9.70
44	17.12 (14.18)	41	6.90

* - average of plots A, B, and C.
** - average of plots B and C.

where HL is the half life (days), t is time after application (days), Xt is the concentration at time t (ng/g), and Xo is the initial concentration (ng/g) from equation (4). The half life of Trifluralin in soil was found to range between 39.9 and 56.5 days with a mean of 46 days in the drained plots. In the nondrained plot the estimated half life was 43 days. There was no significant difference in the estimated half-life of Trifluralin between the drained and nondrained plots (t-test comparison at 1% significance level).

Table 23 presents the regression equations relating the observed Trifluralin concentrations in the soil (0-15 cm) with the days after application during 1991 and 1992 cropping seasons. Also included in the table are the estimated half-life of Trifluralin. The regression equation used was:

$$y=a+b\ln x \qquad (6)$$

where:

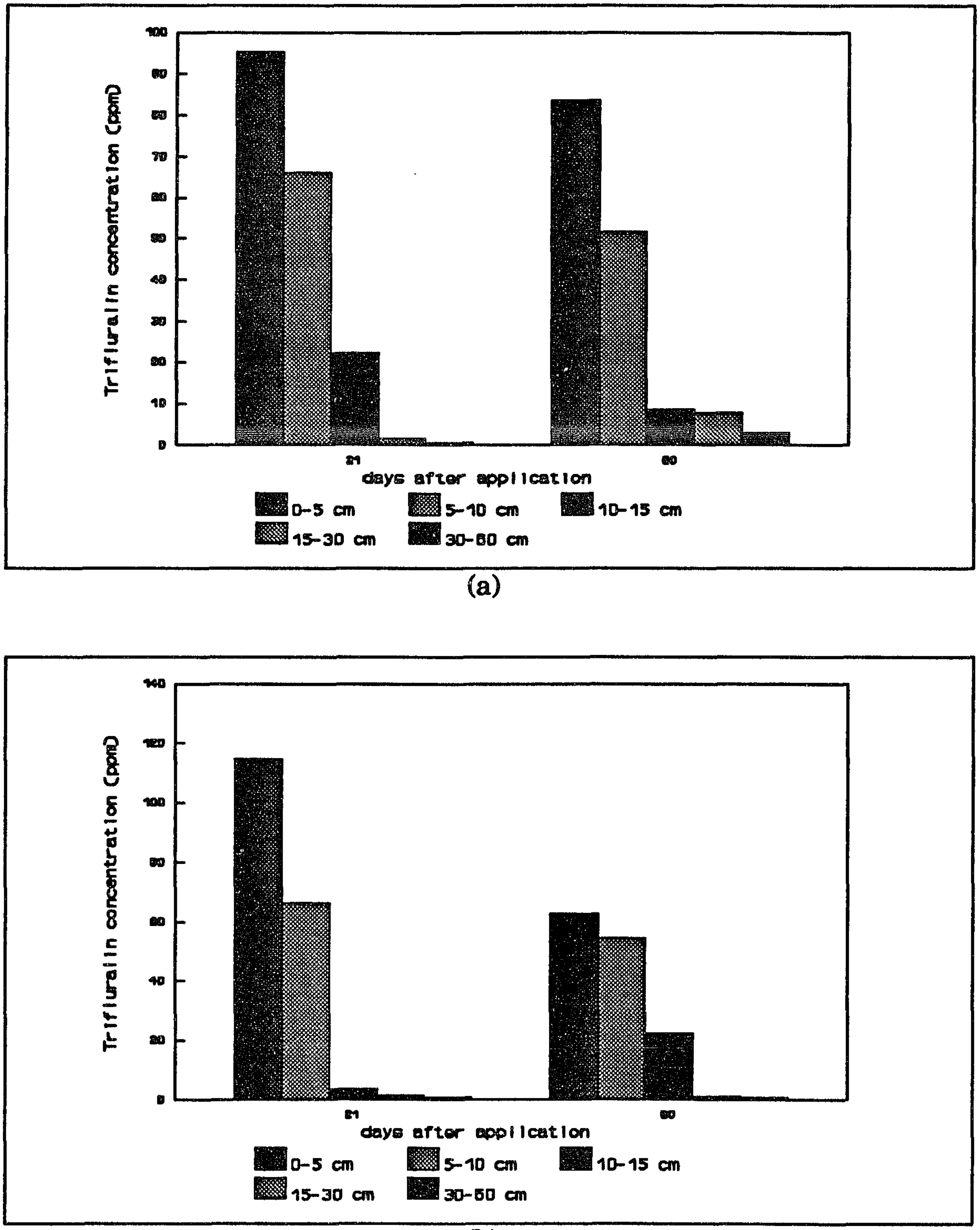
y - time after application, days;
x - concentration at time y, ng/g;
a - intercept of the regression line;
b - regression coefficient;
R - correlation coefficient.

Figure 23 presents the Trifluralin concentration in the soil (0-60 cm) from the drained and nondrained plots, respectively, in 1991. Each plot illustrates the pattern of Trifluralin distribution in the root zone which indicates the leaching characteristic of the herbicide. The low concentrations observed in the lower soil horizons even after 60 days after the application compliments earlier observation (on the subsurface outflow) suggesting a low leaching property of Trifluralin. This can also be discerned from the observed concentrations in the monitoring well samples from the 1 m and 2 m depths (Table 24) which supports the observation. The Trifluralin concentration from the 1 m depth exhibited a downtrend pattern with time which was probably due to leaching combined with chemical degradation. The 2 m depth concentration increased with time although at a minute changes for the same reason.

Table 23. Regression parameters relating observed Trifluralin concentration in the soil (0-15 cm) with days after application and the estimated half life of Trifluralin in soil.

Plot	a	b	R	HL*
1991 Cropping season				
Drained plots	385.13	- 78.28	- 0.94	46.0
Nondrained plot	298.33	- 61.52	- 0.96	42.6
1992 Cropping season				
Drained plots	94.74	- 21.26	- 0.88	45.4
Nondrained plot	73.32	- 20.60	- 0.91	42.2

* - estimated mean half life.



(a)

(b)

Figure 23. Trifluralin concentration in the soil profile (0-60 cm) in the drained (a) and nondrained (b) plots in 1991 cropping season.

Table 24. Trifluralin concentration in the monitoring wells at 1 m and 2 m depths during the 1991 and 1992 cropping seasons.

Depth	1991 Cropping season				1992 Cropping season			
	Drained plots*		Nondrained plot		Drained plots**		Nondrained plot	
	DAA	Concentration (μg/L) [s.d.]	DAA	Concentration (μg/L)	DAA	Concentration (μg/L) [s.d.]	DAA	Concentration (μg/L)
1	30	0.050 (0.01)	5	0.083	6	0.200 (0.05)	34	0.246
2		0.028 (0.003)		0.046		0.207 (0.091)		
1	35	0.031 (0.009)	27	0.060	24	0.096 (0.009)	67	0.06
2		0.042 (0.01)		0.063		0.186 (0.025)		
1	61	ns	60	0.058	43	0.083 (0.117)	99	0.093
2		0.048 (0.012)		0.045		0.138 (0.017)		
1	ns	-	ns	-	74	0.094 (0.004)	ns	-
2		-		-		0.125 (0.045		-

* - averaged from plots A, B, and C. ** - averaged from plots B and C. ns - no sample

4.3.B. Metolachlor

Metolachlor {2-chloro-N-(2-ethyl-6-methylphenyl)-N-2(methoxy-1-methylethyl) acetamide is a wide spectrum herbicide listed for annual grass weeds. Representative examples of weeds controlled include barn yard grass, crab grass, fox tails, and many others. Several formulations either as a single element or in combination with other herbicide formulations are available in the market. Its nomenclature, physical and chemical properties and other information regarding this herbicide is well documented in the Herbicide Handbook (1989) of the Weed Science Society of America.

Listed in Table 25 are the Metolachlor concentrations in the runoff in 1991 and 1992 cropping seasons. As can be noted from the table, the date listed just below the DAA shows the date of the herbicide application. The succeeding numbers in the column indicate the time of runoff occurrences after the herbicide application. In both seasons the highest herbicide concentration recovered was contained in the samples from the first runoff event. The peak concentration was 628 µg/L (0 daa) during the 1991 cropping season; it was 298 µg/L (12 daa) in 1992. A steady decrease in the concentration occurred during the remainder of the study which indicates a gradual degradation of metolachlor in the surface soil.

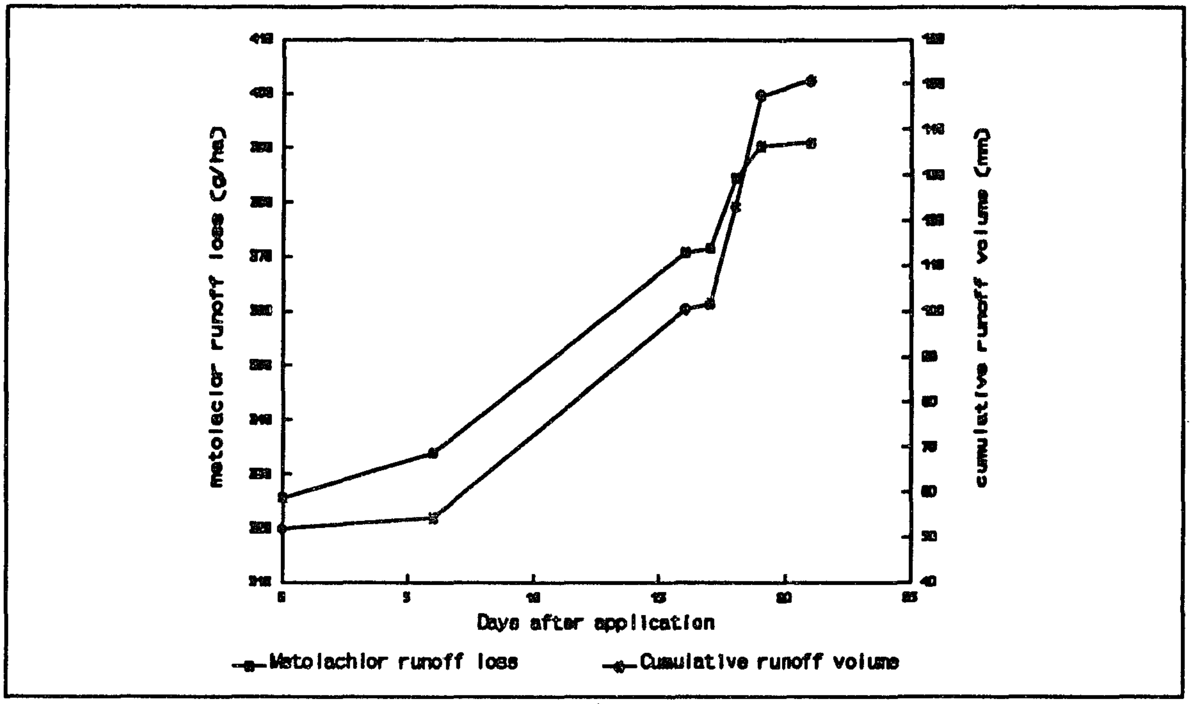
Presented in Figure 24 are the plots of cumulative Metolachlor runoff loss and cumulative runoff volume during the 1991 and 1992 cropping seasons. The runoff loss was estimated on per storm basis and the estimated

Table 25. Metolachlor concentration in the runoff during the 1991 and 1992 cropping seasons.

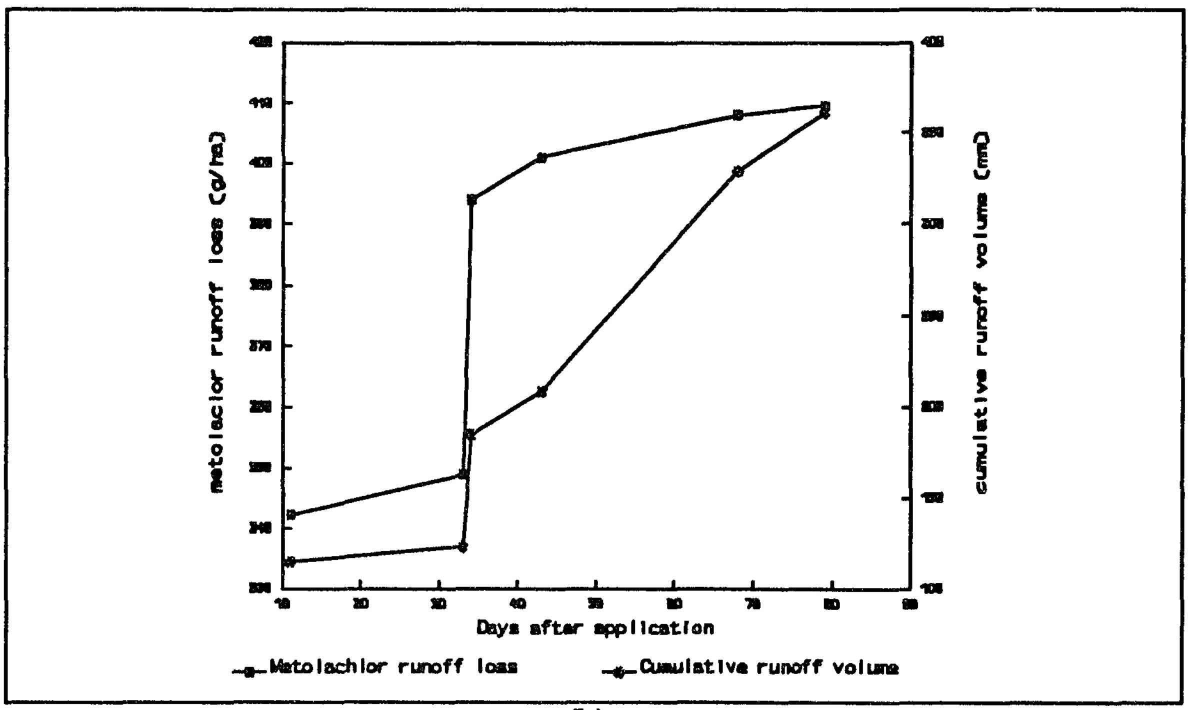
1991 Cropping season		1992 Cropping season	
DAA (June 18)	Concentration (μg/L)	DAA (June 19)	Concentration (μg/L)
0	628.00	11	298.40
6	354.00	33	78.96
16	79.60	34	72.63
17	64.40	43	30.09
18	60.00	68	5.74
19	24.48	70	5.22
21	18.00	133	3.19

total Metolachlor loss was 391 g/ha (1991 cropping season) and 373 g/ha (1992 cropping season). The observed cumulative runoff in 1992 cropping season was 365 mm and was larger than the cumulative runoff during the 1991 cropping season (151 mm) by 41%. The first surface runoff after the herbicide application was 51.8 mm (1991) which occurred immediately after the application. It was responsible for 83% of the total runoff loss. During the 1992 cropping season, the first runoff was 114.7 mm (11 daa) and it was responsible for 342.2 g/ha runoff loss (83.5% of the total Metolachlor runoff loss for the season).

The concentrations of Metolachlor in the soil (0-15 cm) are listed in Table 26. Calculation of its half-life in the soil yield 19.74 to 34.25 days with



(a)



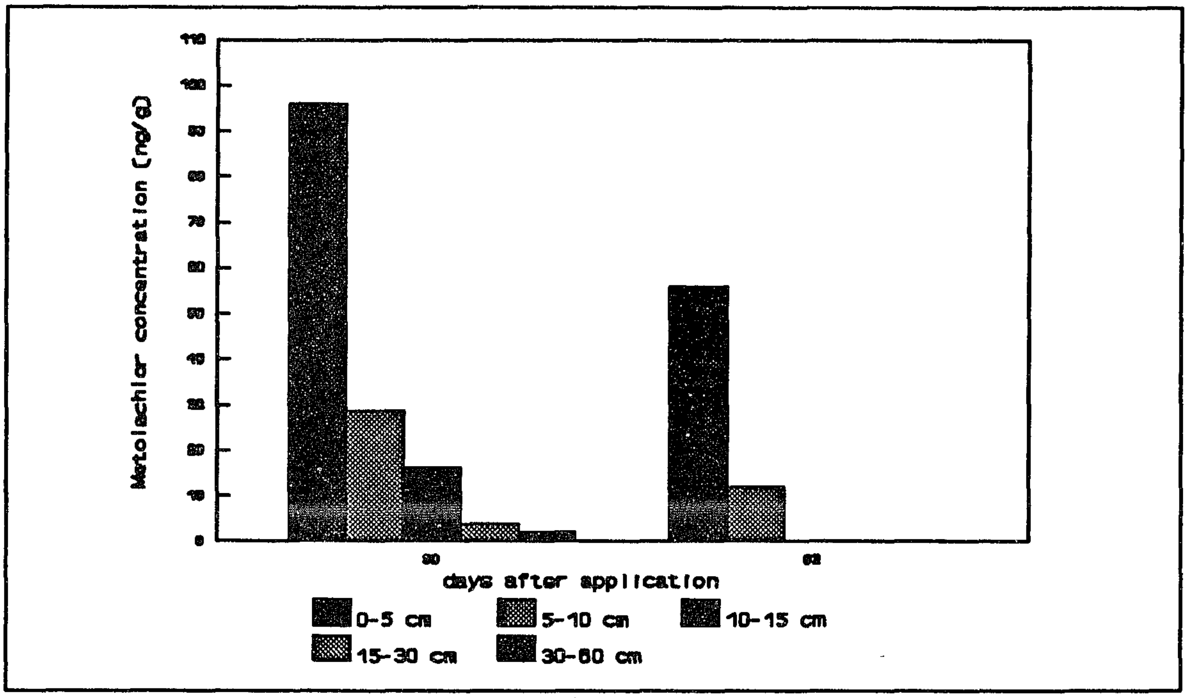
(b)

Figure 24. Cumulative Metolachlor runoff loss and cumulative runoff in the nondrained plot in 1991 (a) and 1992 (b) cropping seasons.

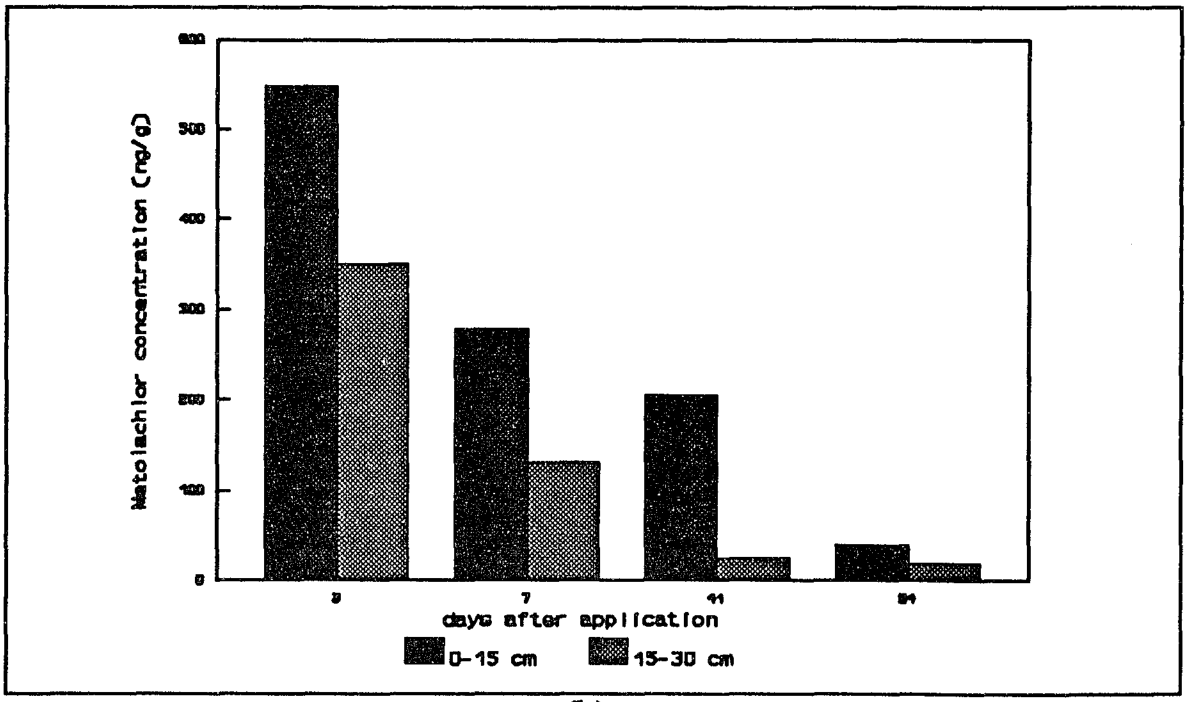
a mean of 27 days. The half-life was estimated using the equation (5) as discussed in the sub-section on Trifluralin. Linear regression between the observed concentration and the days after application in the soil (0-15 cm) yield a correlation coefficient (R) of -0.80 and -0.97 in 1991 and 1992 cropping seasons, respectively. The regression coefficients were 147.32 (a) and -26.28 (b) during the 1991 cropping season while a = 225.5 and b = -36.20 in 1992 cropping season.

Presented in Figure 25 are the concentration of Metolachlor in the soil profile (0-60 cm) at 30 and 62 daa's during the 1991 cropping season and 3, 7, 41, and 94 daa's during the 1992 cropping season. The concentrations show a decreasing distribution pattern in the profile. For example the concentration of Metolachlor in the top (0-5 cm) layer on 30 daa was about 96 ng/g while in the 30-60 cm layer it was 2 ng/g. Later, on the 62 daa, the top layer concentration was reduced to 56 ng/g while at the 10 cm depth down to 60 cm depth, the concentration was below the detection limit of 0.072 ng/g in the gas chromatography analysis. The same results were observed from the soil profile in the 1992 cropping season. The concentrations were decreasing with time in each of the layers which indicates that degradation is continuing in the soil profile where the chemical is present.

Presented in Table 27 are the concentrations of Metolachlor in the samples taken from the 1 m and 2 m depth monitoring wells. Similar to the concentrations observed from the soil profile, the concentration of Metolachlor



(a)



(b)

Figure 25. Concentration of Metolachlor in the soil profile in 1991 (a) and 1992 (b) cropping seasons.

Table 26. Metolachlor concentration in the soil (0-15 cm) during the 1991 and 1992 cropping seasons.

1991 Cropping season		1992 Cropping season	
DAA (June 18)	Concentration (ng/g)	DAA (June 19)	Concentration (ng/g)
17	204.72	3	547.00
22	62.31	7	278.75
30	47.35	41	205.00
62	36.63	94	38.51
73	28.67	ns	-

Table 27. Concentration of Metolachlor in the 1 m and 2 m samples from the monitoring wells during 1991 and 1992 cropping seasons.

1991 Cropping season			1992 Cropping season		
DAA	Concentration (μg/L)		DAA	Concentration (μg/L)	
	1 m depth	2 m depth		1 m depth	2 m depth
17	205.82	16.82	18	72.06	2.13
30	223.78	29.74	50	28.56	0.88
62	3.61	205.38	77	16.02	1.69

in the well samples decreased with time in the 1 m depth while small increases were observed in the 2 m depth. The concentration increases in the 2 m depth indicate the amount of the chemical leaching from the upper soil layers which was probably reduced by degradation.

4.3.C. Metribuzin

Metribuzin {4-amino-6-t-butyl-3-(methylthio-1,2,4-triazine-4-cyanophenyl octanoate) is a pre-emergent herbicide used in weed control to several crops including wheat, barley, cotton, and soybeans, among others. The description of properties and characteristics of this herbicide is well documented in the Herbicide Handbook (1989).

Presented in Figure 26 are the Metribuzin concentrations in the surface runoff and the runoff volume at selected daa's during the 1991 cropping season. The highest observed concentration was 119.88 µg/L from the first runoff event (0 daa). The observation supports earlier observations that the time of runoff occurrence after pesticide application determines the chemical concentration in the surface runoff. The amount of chemical lost in the runoff, however, is influenced by the runoff volume. Generally, the higher the runoff volume, the more sediments it contains and the higher amount of chemical will be lost in the runoff. Although the first runoff event was not the largest, it was responsible for 78% of the total runoff loss for the season. Subsequent runoff events although larger than the first runoff volume, did not yield as high concentration as that of the first runoff. The concentration of Metribuzin in the succeeding runoff events decreased substantially. It was probably because the available amount of the chemical retained after a period of time has been amply reduced. The chemical had undergone at least one half life and the amount of the chemical in the soil had been largely reduced.

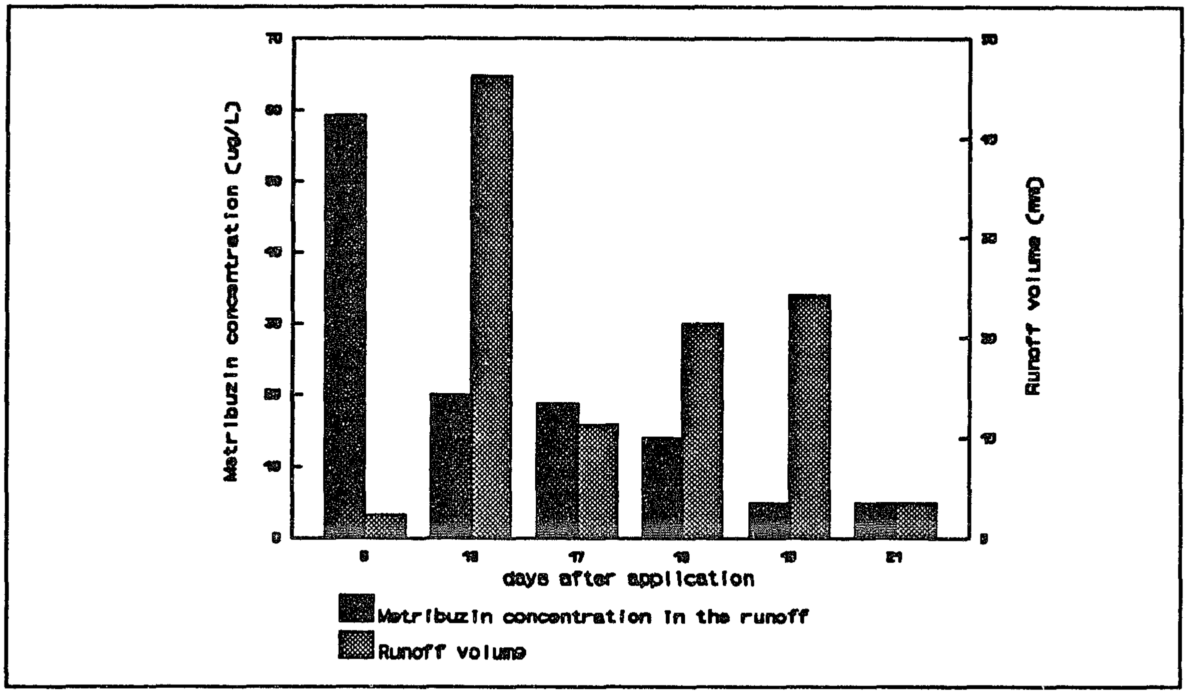


Figure 26. Metribuzin concentration in the surface runoff and the runoff volume at selected days after application of the herbicide in 1991 cropping season.

The graphs of cumulative Metribuzin runoff loss and the cumulative runoff volume are presented in Figure 27. The estimated Metribuzin runoff loss was 79.29 g/ha. The total runoff volume responsible for the loss was 161 mm which occurred in 21 days after the herbicide application.

Listed in Table 28 are the observed concentrations of Metribuzin in the soil (0-15 cm) at selected days after application. The highest concentration was 25.56 ng/g at 17 daa while the lowest was 2.23 ng/g observed 73 days after the herbicide application. Based from these concentrations, the half life of Metribuzin was estimated at 15.91 days. Linear regression between the observed concentration (dependent variable) and the days after application

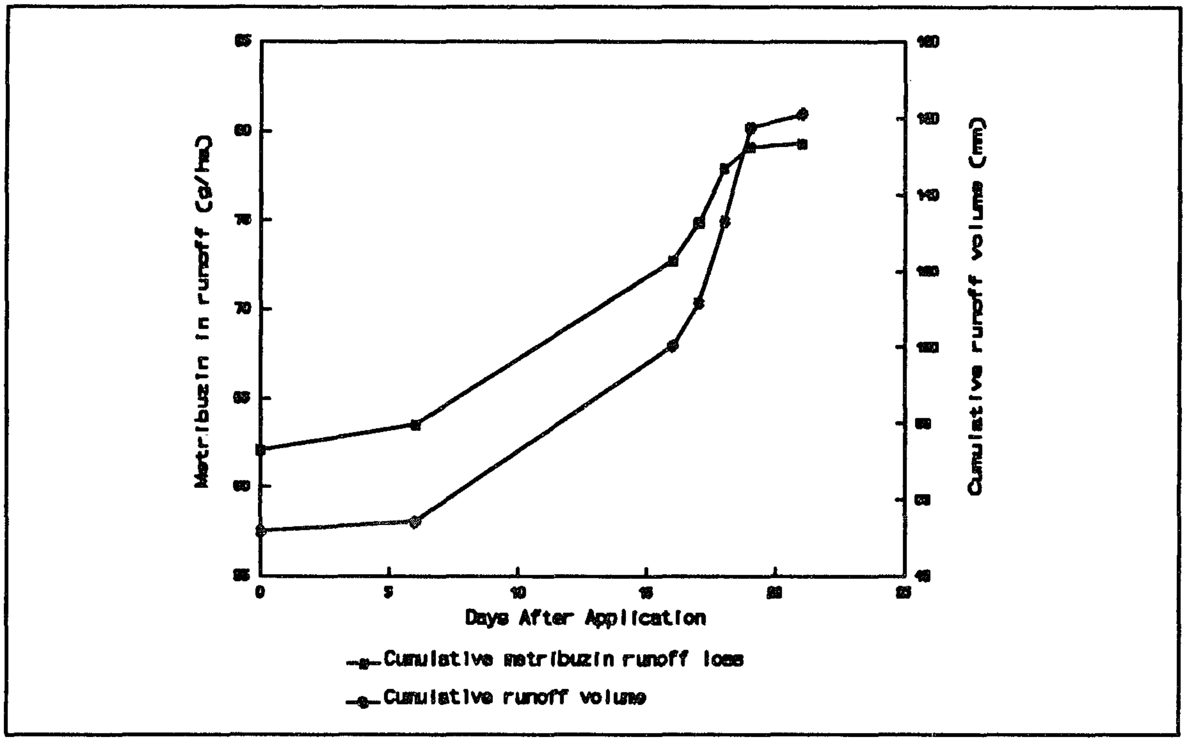


Figure 27. Cumulative Metribuzin runoff loss and the cumulative runoff volume at the nondrained plot during the 1991 cropping season.

Table 28. Observed concentration of Metribuzin in the soil (0-15 cm) at selected days after the herbicide application of 609 g/ha.

1991 Cropping season	
Days after application	Concentration (ng/g)
17	25.56
22	22.64
30	13.86
62	11.63
73	2.23

(independent variable) using equation (6) yielded a correlation coefficient (R) of -0.88 with regression coefficients a and b equal to 96.12 and -22.59, respectively.

Presented in Figure 28 are the observed concentration of Metribuzin in the soil profile (0-60 cm) at 30 and 62 days after application of 609 g/ha. The concentrations show a decreasing distribution with depth in the soil profile. Higher concentrations were observed in the upper soil layers but became less and less as the depth increased. The distribution may be a good indicator of the soil adsoption characteristic of the chemical. Its very low concentration in the lower layers suggest a low soil adsorption property. The same pattern was observed in the later date. Also, the concentrations show a decreasing pattern with time. As can be noted, the chemical concentration at the 0-5 and 5-10 cm layers were much lower at 62 daa compared with the concentration at 30 daa. And, the chemical concentration in the lower layers were below detection limits of 1.238 ng/g at 62 daa which indicates the short persistence of Metribuzin. This is further supported by the chemical concentrations observed at 1 m and 2 m samples from the monitoring wells presented in Figure 29. At the 1 m depth, the observed concentration was 64.23 μg/li and was decreasing with time while at the 2 m depth, the observed concentration was increasing with time. This indicates that metribuzin is highly soluble, with medium leaching property, and is not highly soil adsorbent (it stays with the soil solution).

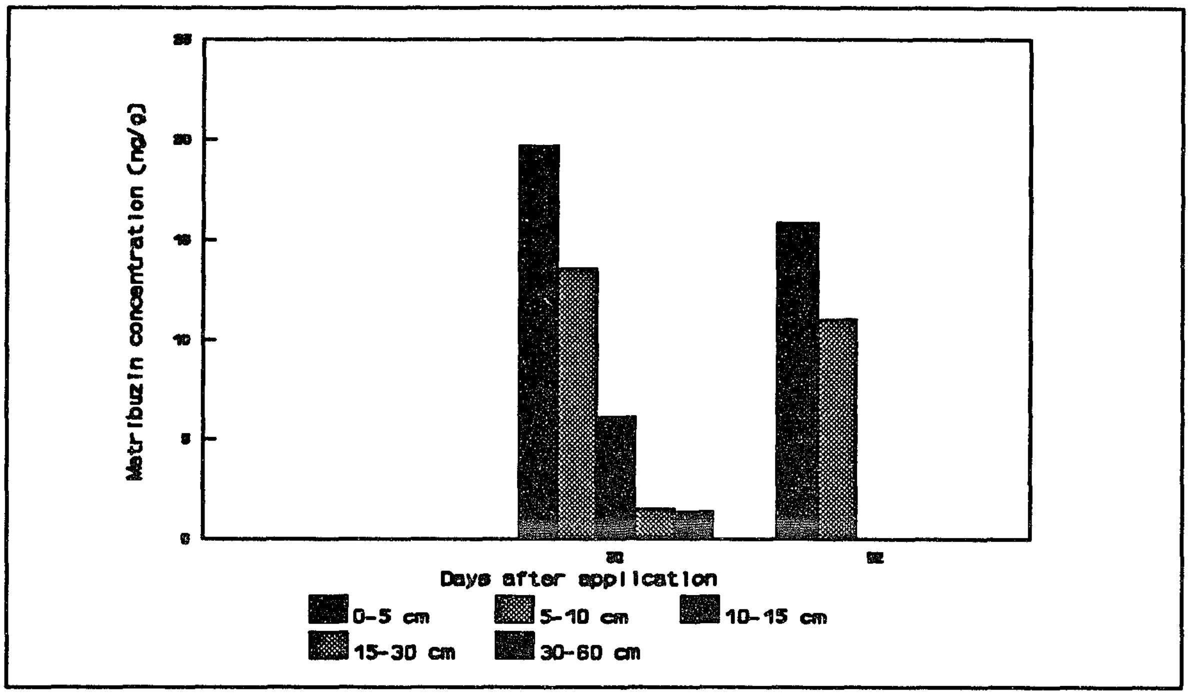


Figure 28. Observed concentration of Metribuzin in the soil profile (0-60 cm) at 30 and 62 days after application of 609 g/ha.

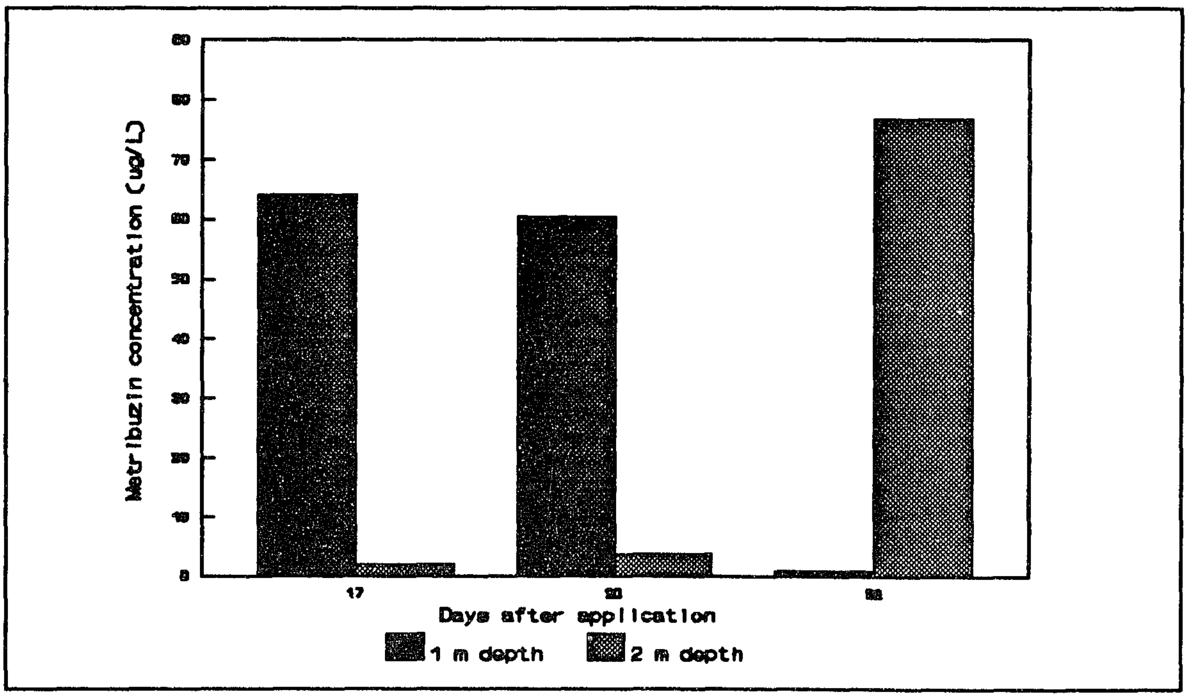


Figure 29. Metribuzin concentrations observed at the 1 m and 2 m samples from the monitoring wells at 17, 30, and 62 days after application.

4.4. Model Simulation and validation

4.4.A. Model simulation

The GLEAMS model was run to verify its accuracy to estimate the fate and movement of the applied herbicides in the experimental plots. Although the primary interest lies with the pesticide loadings, surface response remains a concern in nonpoint source pollution. Surface runoff, percolation, and erosion influence the concentration and amount of chemicals lost or retained in the field as they relate to soil water movement in the root zone.

4.4.A.1. Hydrology component

The surface runoff volume and peak rate, the soil water storage, the percolation and the evapotranspiration were estimated in the hydrology component of GLEAMS. Results of the simulation in hydrology component in general showed that the surface runoff volume was underestimated by the model and the prediction for the percolation was satisfactory. Details are discussed in the following sub-sections.

4.4.A.1.a. Surface runoff

The annual surface runoff volume predicted by the model from the experimental plots were 577.2 mm and 530.6 mm in 1991 and 1992, respectively. The predicted runoff volume from the drained and nondrained plots were similar because the parameter and variable inputs used in the simulation were the same in both plots. In 1991 the annual surface runoff volume from the drained plots was 612.8 mm while it was 854.2 mm in the nondrained plots (see Table 15).

Presented in Table 29 are the mean monthly observed and model predicted surface runoff volume. In all months except October and November, the model underestimated the surface runoff. The mean annual surface runoff volume in 1991 was 733.5 mm. The model underestimated the mean annual surface runoff volume by 21% in 1991. The relationship between the observed average monthly surface runoff volume and the model-predicted monthly surface runoff volume is:

$$Qp=0.59+0.72Qo \tag{7}$$

where Qp is the predicted surface runoff volume and Qo is the observed surface runoff volume with a correlation coefficient (R) of 0.99. Similarly in 1992, the mean annual surface runoff volume of 914 mm was underestimated by the model by 58%. The model severely underestimated the surface runoff by 85% in the month of August. The runoffs in the months of May and April however were slightly overestimated by the model. The regression equation relating the observed and the predicted monthly surface runoff volume (R = 0.85) is:

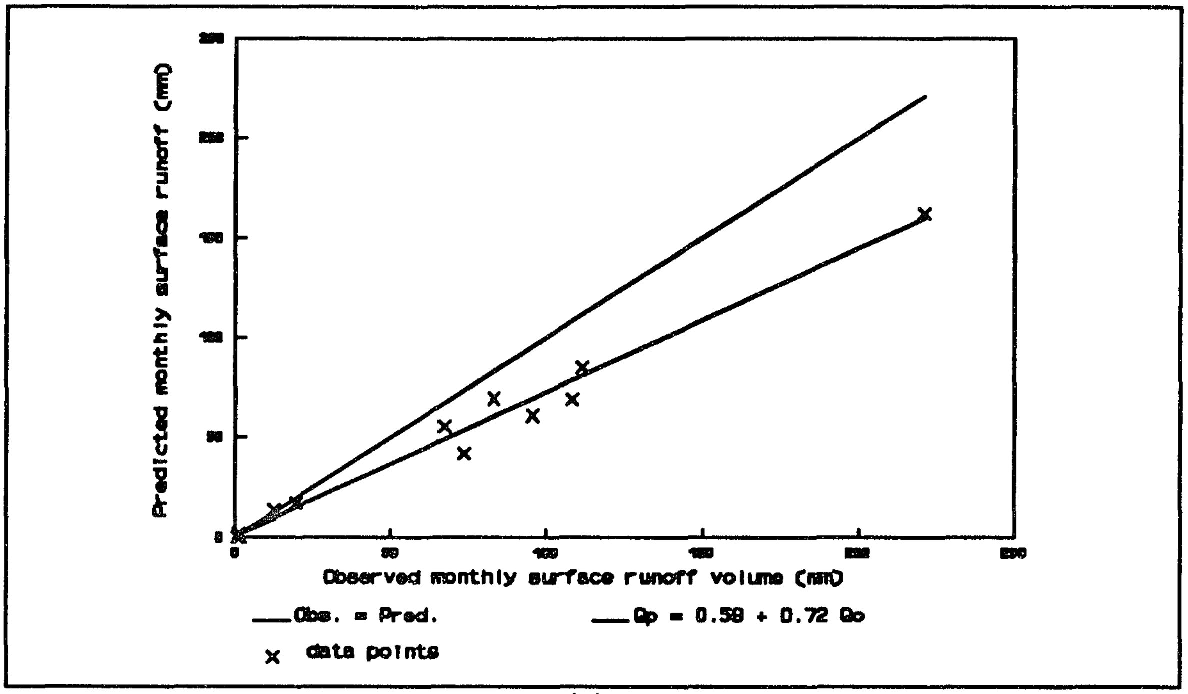
$$Qp=-0.98+0.59Qo \tag{8}$$

Table 29. Mean monthly observed and GLEAMS model predicted surface runoff in 1991 and 1992 at the experimental plots.

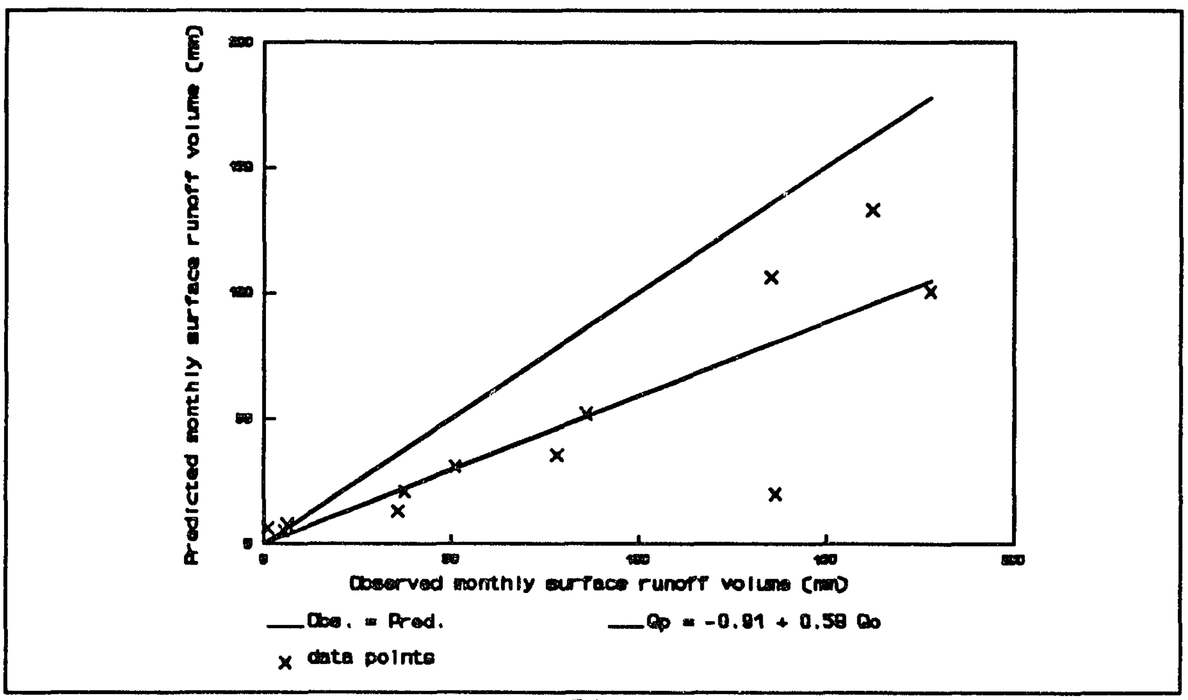
Month	1991			1992		
	Obs* (mm)	Pred (mm)	% Diff**	Obs* (mm)	Pred (mm)	% Diff**
Jan	95.5	61.0	36.1	162.4	132.7	18.3
Feb	83.1	69.3	16.6	177.8	100.3	43.6
Mar	67.1	55.3	17.6	51.1	30.8	39.7
Apr	111.6	85.0	23.8	6.3	7.7	-18.2
May	221.2	162.6	26.5	1.1	6.4	-82.8
Jun	108.3	68.9	36.4	135.4	106.3	21.5
Jul	73.7	41.8	43.3	78.4	35.7	54.5
Aug	19.7	17.3	12.2	136.3	19.9	85.4
Sep	1.8	0.0	100	35.7	13.2	63.0
Oct	12.5	13.8	-9.4	5.4	5.1	5.6
Nov	1.2	2.3	-47.8	86.1	51.8	39.8
Dec	0.6	0.0	100	37.7	20.7	45.1
Annual	733.5	577.2	21.3	913.7	530.6	41.9

* - average of drained and nondrained plots.
** - negative % difference denotes predicted is larger than observed value.

with the Qp and Qo variables previously defined. Shown in Figure 30 are the plots of the relationship between the observed versus predicted surface runoff volume in 1991 and 1992 with an equal value line (with slope of 1) representing observed values equal to predicted values. The slope of the regression line was statistically different from 1.0 (t-test, $p > 0.05$).



(a)



(b)

Figure 30. Observed versus model-predicted monthly surface runoff volume in the experimental plots in 1991 (a) and 1992 (b).

The underestimation of the annual surface runoff volume was probably brought about by the model assumption in the percolation routine of no impermeable layer in the soil profile; or if present, is located deep in the profile. This assumption implies that the water in the root zone can freely move downward until the soil moisture was depleted to field capacity. Field capacity is defined as the moisture condition when the redistribution rate approaches zero and was previously defined as (Rich, 1971) " the percentage of water remaining in a soil 2 or 3 days after having been saturated, and after free drainage has practically ceased". The assumption in the model does not account for the formation of a water table. Under shallow water table conditions, the soil water does not percolate deep in the soil profile.

There are many areas in the Lower Mississipi Valley where a shallow water table exist. For example at the Ben Hur Research Farm, a semi-permeable layer is located within 110 cm to 160 cm from the soil surface. The shallow water table in the experimental plots fluctuates from the soil surface to about 150 cm deep (see Figures 13-17 and Appendix A). The presence of a shallow water table in the experimental plots violates the model assumption.

The surface runoff is estimated in the model using the modified US Soil Conservation Service curve number technique (Williams and Nicks, 1982) where the volume of surface runoff is a function of the rainfall and a retention parameter based, among other variables, on the antecedent soil moisture condition in the root zone. In soils with a shallow water table, the moisture content in the root zone is well above the field capacity thus the model underestimated the soil moisture content. And with the soil moisture content underestimated, the retention parameter will be overestimated leading to higher infiltration rate and less surface runoff.

In the drained plots, the subsurface drains lowered the water table and drained the soil moisture content to conditions close to field capacity condition. The surface runoff volume estimate of the model was only 5.81% less than the observed surface runoff volume (1991). This indicates a need for further study on the present algorithms of the model for possible inclusion of the influence of a shallow water table in the prediction of surface runoff; other related parameters such as infiltration and moisture distribution and movement in the soil profile are of interest as well. The surface runoff volume is influenced by the moisture content in the root zone.

4.4.A.1.b. Percolation

Percolation in the model is estimated as a function of infiltration, soil storage volume, soil moisture regime, saturated hydraulic conductivity, and a storage coefficient (a function of soil water travel time in the profile). If the volume of water stored in the soil plus the infiltrated amount at a given soil layer is less than field capacity, percolation is not predicted to occur. The observed average subsurface drain outflow and the model-predicted percolation from the experimental plots for 1991 and 1992 are presented in Table 30. The subsurface drain outflow was used to compare with the model

Table 30. Observed average subsurface drain outflow and model-predicted monthly percolation from the experimental plots in 1991 and 1992.

Month	1991		1992	
	Observed Drain Outflow (mm)	Predicted Percolation (mm)	Observed Drain Outflow (mm)	Predicted Percolation (mm)
January	85.09	70.69	103.31	79.87
February	51.22	73.67	86.23	108.65
March	48.05	56.77	43.05	25.07
April	73.96	39.93	11.67	8.50
May	127.27	149.04	0.16	3.97
June	33.79	62.52	60.30	62.53
July	30.80	43.85	31.10	39.34
August	0.07	0.00	0.56	3.44
September	1.31	0.00	8.15	0.00
October	0.14	0.00	4.90	0.00
November	0.46	0.00	27.48	20.91
December	3.86	0.00	7.93	35.78
Annual	456.0	496.5	384.8	388.1

predicted percolation in this study. The subsurface outflow was assumed as being the best practical alternative in the absence of another measurement relevant to percolation and may be a reasonable representative of actual percolation. The annual percolation as predicted by the model totalled 496.5 mm in 1991 and was 388 mm in 1992. The model estimates were not significantly different from the observed subsurface drainage outflow (t-tests, $p > 0.01$) considering that the amount of subsurface outflow is subject to the efficiency of the subsurface drains to conduct the outflow. The relationship between the observed subsurface drain outflow and the model predicted percolation for 1991 is:

$$Pred. = 2.53 + 1.02 Obs. \tag{9}$$

with a correlation coefficient of R = 0.92; for 1992, the relationship is described by the regression equation (R = 0.91):

$$Pred. = 2.82 + 0.92 Obs. \tag{10}$$

4.4.A.1.c. Evapotranspiration

The evapotranspiration is estimated by the model using the technique developed by Ritchie (1972) which is a modification of the Penman method (1948). Under the Ritchie's model, soil evapotranspiration and plant transpiration are estimated separately and summed. Ritchie introduced the leaf area index (LAI) as a factor which affect soil evaporation and plant transpiration rates. The original Penman method used crop coefficients to estimate actual evapotranspiration. The reader is referred to the paper for the detailed explanation of Ritchie's methodology.

Presented in Table 31 are the predicted monthly evapotranspiration for 1991 and 1992 in the experimental plots. No comparison was made due to the absence of observed evapotranspiration measurements. However, a study

Table 31. Predicted monthly evapotranspiration for 1991 and 1992 from the experimental plots.

Month/Year	Model-predicted Evapotranspiration (mm)	
	1991	1992
January	33.4	45.9
February	34.7	53.6
March	45.6	65.8
April	55.0	66.0
May	89.2	43.7
June	84.6	83.8
July	108.6	135.7
August	146.2	159.7
September	121.7	118.6
October	39.0	65.5
November	46.4	44.4
December	36.4	41.1
Total	841.0	923.7

conducted by Bengtson and Carter (1983) using the CREAMS model (Knisel, 1980) which also uses the Ritchie's model estimated an average annual evapotranspiration of 876 mm for Baton Rouge, Louisiana. A direct water budget measurements they made on a subsurface drainage research in the area showed an annual average of 980 mm which is about 12% over the model-estimate. Hence, it is safe to assume that evapotranspiration was underestimated by the model due probably to the underestimation of the soil moisture content in the root zone.

4.4.A.1.d. Soil water storage

A storage routing technique is used to simulate redistribution of the infiltrated water in the root zone. A local water balance is employed to account for soil water storage considering the soil water content of the previous day, the incoming water from infiltration, and the depletion of water due to evapotranspiration. And since the model does not account for a shallow water table, no upward water movement from the water table nor from the saturated zones to the unsaturated soil zones above the water table are accounted for by the model. This may result in the underestimation of the amount of soil water stored in each of the computational layers. The underestimation of the soil water content affected not only the estimate of evapotranspiration loss but also the infiltration rate and eventually led to the underestimation of the surface runoff.

4.4.A.2. Erosion-sediment yield component

The observed and predicted average monthly soil loss for both the drained and nondrained plots are presented in Table 32 for 1991 and 1992. The model-predicted average annual soil loss from the drained plots is 3,864 kg/ha in 1991 while it is 4,183 kg/ha in 1992. For the nondrained plots, the average annual soil loss predicted by the model are 3,648 kg/ha and 3,985 kg/ha for 1991 and 1992, respectively. The model estimated soil erosion poorly.

Table 32. Observed and model-predicted average monthly soil loss from the drained and nondrained plots in 1991 and 1992.

Month	1991				1992			
	Drained Plots		Nondrained Plots		Drained Plots		Nondrained Plots	
	Observed (kg/ha)	Predicted (kg/ha)	Observed (kg/ha)	Predicted (kg/ha)	Observed (kg/ha)	Predicted (kg/ha)	Observed (kg/ha)	Predicted (kg/ha)
January	2911.40	462.53	3180.35	437.91	5938.10	983.73	7036.06	935.47
February	369.40	408.80	773.30	387.19	521.10	649.58	821.37	614.86
March	605.27	352.34	883.00	333.87	354.71	280.49	488.16	266.87
April	1137.13	539.45	1108.50	493.56	9.70	65.16	10.59	61.96
May	1129.47	1018.97	1830.95	956.66	2.15	42.77	3.49	40.35
June	1842.87	441.94	2915.30	416.30	1693.44	996.37	1845.77	942.29
July	1114.16	247.03	1838.85	233.00	1052.41	280.20	1736.77	279.38
August	120.07	207.99	587.65	98.74	1075.57	203.91	1901.56	196.34
September	7.60	0.00	32.55	99.11	290.82	126.69	399.77	120.47
October	33.97	161.59	192.00	154.47	24.07	86.45	53.10	82.28
November	2.33	23.65	16.35	22.48	198.16	324.25	291.84	307.94
December	0.70	0.00	9.55	0.00	142.30	143.46	489.98	136.89
Annual	9274.37	3864.28	13368.35	3647.51	11302.53	4183.07	15078.51	3985.22

For the drained plots, the model underestimated soil erosion by 61% and 63% in 1991 and 1992, respectively. For the nondrained plots, the model underestimated soil erosion by 73% in 1991 and 74% in 1992.

The model underestimation of the soil erosion may have stemmed from a probable underestimation of the EI_{30}. The EI_{30} is used to measure the rainfall erosivity or the ability of rain to detach soil particles and cause soil erosion. It is one of the critical factors in the Universal Soil Loss Equation (USLE). The underestimation of the EI_{30} may be traced from the conditions underlying its development. It was developed based from an empirical regression relating it to daily amount of long-duration rainfall (Wischmeier and Smith, 1978). The empirical regression equation relating EI_{30} with daily rainfall amount may not be capable of accounting for the high intensity-short duration rainfall in Baton Rouge.

Another probable cause is the underestimation of the runoff volume from these high rainfall events. The model underestimation of the soil moisture condition in the root zone prior to rainfall grossly affected the amount of the surface runoff volume (as discussed in the hydrology component). A third factor which probably caused the underestimation of the soil loss was the underestimation of the runoff's sediment transport capacity. The sediment transport capacity of the runoff is influenced by the peak runoff rate which is directly affected by the slope and slope length of the plots. The relatively flat slope of the plots rendered the peak runoff rate to be underestimated. With the underestimation of the EI_{30}, the runoff volume and the peak runoff rate, it was not surprising that soil loss through erosion was underestimated by the model by an average of 70%.

4.4.A.3. Pesticide component

The pesticide component of the model estimates the concentration and quantity of pesticides contained in the surface runoff and in the percolation below the root zone. The model estimates closely approximated the observed surface runoff and percolation losses for all the three herbicides monitored in the study. For example, the observed mean runoff loss of Trifluralin in the 1991 season was 0.51 g/ha which was about 0.03% of the applied herbicide. The model estimate of the Trifluralin runoff loss was 1.23% of the applied amount or an overprediction of 1.2%. During the 1992 season, the model overestimated Trifluralin loss in the surface runoff by 0.07 per cent. Details of the data are listed in Table 33 which presents the observed and GLEAMS predicted surface runoff loss of Trifluralin, Metolachlor, and Metribuzin during the 1991 and 1992 cropping seasons. For Metolachlor, the model underestimated the runoff loss by 2.2 and 4.8 percent in 1991 and 1992, respectively. Metribuzin runoff loss was also underestimated by the model by 2.9 percent.

Listed in Table 34 were the observed Trifluralin loss in the subsurface outflow and the model predicted percolation loss in 1991 and 1992 cropping seasons. The model underpredicted the amount of percolation loss in both

Table 33. Observed and GLEAMS predicted surface runoff loss of Trifluralin, Metolachlor, and Metribuzin during the 1991 and 1992 cropping seasons.

Herbicide Name	1991 Cropping season								
	Drained Plots		Nondrained Plot		Mean		% of Applied Herbicide		% Diffe-rence
	Obser-ved (g/ha)	Gleams (g/ha)	Obser-ved (g/ha)	Gleams (g/ha)	Obser-ved (g/ha)	Gleams (g/ha)	Obser-ved (g/ha)	Gleams (g/ha)	
Trifluralin	0.77	16.82	0.24	11.44	0.51	14.14	0.03	0.84	0.81
Metolachlor	-	-	391.97	328.81	391.97	328.81	14.18	11.91	-2.27
Metribuzin	-	-	79.29	61.58	79.29	61.58	13.02	10.09	-2.93
1992 Cropping season									
Trifluralin	0.24	0.82	0.82	0.82	0.53	0.82	0.03	0.05	0.02
Metolachlor	-	-	373.73	241.45	409.73	241.45	14.86	8.75	-6.11

Table 34. Observed Trifluralin loss in the subsurface outflow and the GLEAMS predicted percolation loss in 1991 and 1992 cropping seasons.

Cropping season	Observed (mg/ha)	GLEAMS (mg/ha)	% of AppliedHerbicide Observed	Gleams	% Diffe-rence
1991	146.16	22.17	0.0087	0.0013	0.0074
1992	0.073	0.016	0.0043	0.0010	0.0033

seasons although the predicted percolation was larger than the observed subsurface drain outflow. This indicates the low leaching characteristic of Trifluralin and agrees with earlier observation. The small amount of Trifluralin loss in the percolation suggests that the main pathway of Trifluralin loss is through the surface runoff which would imply that the herbicide is highly soil adsorbent.

4.4.B. Model validation

Validation is generally a means to evaluate and confirm the integrity and usefulness of a model. Models are usually judged according to the closeness and reasonableness of simulation results with an observed data which are measured with minimal or acceptable errors. However, as models were designed to depict the real world, it is seldom that a model totally represents actual conditions considering the many uncertainties inherent to field conditions. A model may not be able to predict exact values, but if results are within acceptable ranges, it may be deemed as satisfactory and useful. The modeler should, therefore, be concerned not only with predicted values being equal to observed values but also should study and comprehend the processes involved in the simulation and see if results are reasonable.

The GLEAMS is a mathematical model developed for field sized areas to evaluate the effects of agricultural management systems on the movement of agricultural chemicals within and through the root zone. Simulation using the GLEAMS model undertaken for two consecutive years (1991 and 1992) showed that the average surface runoff volume and soil erosion loss were underestimated by the model on both simulated years by 21% and 70%, respectively. Predicted percolation values were found not significantly different from the observed subsurface drain outflow. Pesticide runoff losses were within reasonable range with observed values.

CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

This study was conducted to assess the movement of agricultural chemical contaminants in alluvial soils with a shallow water table in a warm, humid environment. Bromide, a non-adsorbent tracer, was used to assess the pathway of water and solute in the soil profile. The movement and fate of three frequently used herbicides in the Lower Mississippi Valley were determined. The data from the herbicide study were used to compare with GLEAMS model simulation results to validate the pesticide component of the model in estimating chemical transport in soils with a shallow water table.

The study was conducted at the Ben Hur Research Farm of the Louisiana Agricultural Experiment Station. Five relatively flat plots (< 0.2% slope) were used in the study; three plots were drained (fitted with subsurface drainage system) and two plots were surface drained (referred to as nondrained plots in this study). Climatic data such as precipitation, relative humidity, maximum and minimum temperature, and solar radiation were measured and recorded at the agriclimatic station adjacent to the experimental plots. Agriclimatic data recording was automated and data files are maintained with the Louisiana AgriClimatic Information Systems of the LSU Agricultural Center.

Data analysis on precipitation showed an erratic monthly distribution based on the long term normal rainfall pattern. Some months yield as high as 3.5 and 2.5 times the normal rainfall while in some months the precipitation was only 41% and 57% of the normal rainfall. The variability in the observed monthly rainfall distribution presents a difficulty in predicting a seasonal pattern for the research area. The observed annual precipitation was 27% and 30% larger than the normal rainfall in 1991 and 1992, respectively.

Analysis of the drainage discharge from the experimental plots showed that larger amounts of surface runoff flowed off the nondrained plots compared with the runoff volume from the drained plots. The subsurface drainage reduced the moisture content of the soil layers above and near the drains resulting to higher infiltration and consequently reduced the amount of surface runoff. The total drainage (surface and subsurface) discharge from the drained plots, however, was larger by 8 to 20 percent than that from the nondrained plots. As the amount of soil loss is directly related to the surface runoff volume, the observed mean soil loss from the nondrained plots was 28% higher than the soil loss from the drained plots.

The measurements made on the water table elevations showed that it fluctuated between the soil surface and 150 cm in the soil profile. The large amounts of rainfall in the research area and the presence of a semi-permeable layer located at about 110 cm down the soil profile aided in the formation of a shallow water table in the plots. A shallow water table indicates an excessive water condition in the upper soil profile which can adversely affect the growth of crops and subsequently lowers the yield. The SEW_{30} with a threshold of 200 cm-days was used to quantify the water table problems in the experimental plots. The SEW_{30} is a measure of the height and duration of a water table within the top 30 cm of the soil profile. Based from the estimated SEW_{30} values, the nondrained plots exhibited a severe water table problem having an annual average of about 2000 cm-days. The drained plots had an estimated annual mean of 252 cm-days. The low values of SEW_{30} in the drained plots suggests that the soil moisture content in the upper layers were effectively reduced by the subsurface drains. Inspection of the estimated monthly SEW_{30} values would indicate the period from June to December as an ideal cropping season as far as excessive water problem is concerned.

Potassium bromide served as the source of the non-adsorbent tracer. It was applied on one meter square area surrounding each of the two monitoring tubes installed near the cased water table monitoring well in each plot. Water table samples were collected from the tubes, one installed at 1 m depth and the other at 2 m depth. Samples from the monitoring tubes were collected within 2 days after each runoff-producing rain and analyzed for Br contents by ion chromatography. The average Br concentration from the 1 m depths were substantially higher than those from the 2 m depth both from the drained and nondrained plots. This indicates that chemical concentration varies with the water table depth with the higher concentrations in the water table nearest the soil surface. It also suggests that solutes do not migrate deep in the aquifer but stay near the surface of the water table. Higher concentrations were observed from the nondrained plots than those observed from the drained plots at 1 m depth. This indicates the influence of the drainage system in the redistribution of the tracer. The tracer was assumed to be contained in the soil solution and the reduction of soil moisture above and near the subsurface drains presumably reduced the amount of the tracer in the soil solution at the drained plots. The observed mean concentrations at 2 m in the drained plots, however, were significantly higher compared with those in the nondrained plots. This points to the possibility that areas with subsurface drainage system may have higher potential risks of contaminating the lower soil profile than conventionally drained areas. And, the continued detection of the tracer at the 2 m depth in the water table even after 608 daa, albeit in low concentration, indicates the possibility of residue deposition of persistent chemicals not removed by the inherent soil drainage system.

Surface runoff was measured through an H-flume located at the lower end of each plot. Each surface runoff event was sampled by an automatic water sampler in the flume set to take samples every twenty minutes. In the drained plots, the subsurface discharge was directed into a sump equipped with an automatic water sampler and an electric pump for discharging outflow onto a surface drainage ditch. Samples from the sump were collected every 12 days while the flume samples were gathered within two days after each runoff event. All samples were frozen until ready for analysis. Chemical analyses for herbicides were done at the USDA Soil and Water Laboratory using an ECD gas chromatography.

The observed mean surface runoff loss of Trifluralin was 509 mg/ha (0.03% of the applied amount) and was significantly larger compared to the leaching loss in both 1991 and 1992 seasons. Its estimated mean half life in the soil was 46 days in the drained plots and 43 days in the nondrained plots. The observed concentration distribution in the soil profile showed low concentration in the lower layers indicative of its low leaching potential. Observed concentrations from samples collected from the monitoring wells showed a decreasing trend with time. Based from results of analysis, the primary pathway of Trifluralin loss is through surface runoff and chemical decay.

The observed mean surface runoff loss for Metolachlor was about 382 g/ha representing 14% of the applied herbicide. Its estimated mean half life in soil was 27 days. The observed concentration distribution in the soil profile showed a decreasing pattern with depth and with time. Observed concentration in the 1-m and 2-m samples from the monitoring wells showed similar pattern with the distribution in the soil profile. The primary pathway of Metolachlor loss was by surface runoff and low leaching coupled with chemical degradation.

The estimated Metribuzin surface runoff loss was about 79 g/ha representing 13% of the applied herbicide. Its estimated half life was 16 days. The concentration distribution of Metribuzin observed in the soil profile showed a decreasing pattern with depth which indicates that the herbicide has a low soil adsorption property. Observed concentration in the monitoring tube samples showed a decreasing trend with time from the 1-m sample and increasing with time with the 2-m sample. This indicates a medium leaching property of the herbicide Metribuzin.

GLEAMS model simulation results showed underestimation of the mean annual surface runoff by 21%. The maximum root zone moisture content considered by the model was at field capacity due to its assumption of no impermeable layer in the soil profile, or if present, is located deep in the soil profile. A shallow water table was not accounted in the model. A shallow water table, however, was present in the experimental plots due to the large amounts of rainfall in the research area and the presence of a semi-permeable layer in the soil profile. The underestimation of the root zone moisture content may have caused the underestimation of the surface runoff volume. The moisture content of the soil affects the infiltration and subsequently the amount surface runoff. The percolation prediction of the model were relatively close to observed subsurface discharge. The drainage afforded by the subsurface drains probably reduced the root zone moisture content near to field capacity conditions.

The soil loss from the experimental plots was underestimated by the model by an average of 70%. The underestimation may have been caused partly by the underestimation of the rain erosivity factor (EI_{30}) which was developed from an empirical regression relating it with daily amount of long duration rainfall. The empirical regression may not be capable of accounting for the high intensity, short duration rainfall in the research area. Another contributory factor in the underestimation of the soil loss was the underestimation of the amount of surface runoff volume. This was due to the underestimation of the root zone soil moisture regime. A third factor which probably influenced the underestimation of soil loss was the underestimation of the runoff's sediment transport capacity. The sediment transport capacity is influenced by the peak runoff rate which in turn was affected by the ratio of the slope and slope length. The peak runoff rate was probably not attained because the experimental plots were relatively flat (< 2% slope).

The GLEAMS pesticide component simulation results were within an order of magnitude with the observed surface runoff loss for Metolachlor and Metribuzin but Trifluralin loss in runoff was overpredicted by the model. Model predictions were: for Trifluralin, an overprediction of 1.2 and 0.07% from the observed runoff loss (1991 and 1992 cropping seasons, respectively); for Metolachlor, underprediction of 2.25 and 4.77% (1991 and 1992 cropping seasons, respectively); and for metribuzin, underestimation of 2.91% of observed runoff loss.

5.2. Conclusion

Analysis and interpretation of the results of this study point out to the following conclusions:

1. The subsurface drainage system reduced surface runoff volume by 28% by depleting the soil moisture content above and near the drainage line and consequently, soil loss was reduced by 28%.

2. The Summation of Excess Water (SEW) technique can be used as a management tool to identify problems relevant to the farming system i.e., the formulation of the cropping schedule and patterns; the quantification of drainage quality.

3. The observed tracer concentrations indicated that water soluble chemicals do not migrate deep in the aquifer but stay near the surface of the water table suggesting that soils with shallow water tables are more vulnerable to contamination than soils with deep water tables.

4. The primary pathway of disappearance for most agricultural chemicals is through the surface runoff. The estimated average Trifluralin lost in the surface runoff was 509 mg/ha (0.03 % of applied); Metolachlor average loss in runoff was 382 g/ha (14% of applied); and Trifluralin loss in runoff was 79 g/ha (13% of applied).

5. The time of runoff occurrence after the herbicide application significantly affects the amount of chemical lost in the surface runoff.

6. The GLEAMS model prediction on pesticide movement were at reasonable range (within an order of magnitude with observed data). Surface runoff volume and soil loss, however, were underpredicted by an average of 21% and 70%, respectively.

5.3 Recommendation

There were many points of interest and questions encountered during the course of the study. Recommendations are thus in order and the following are hoped to provide some information and guidance to future research:

1. The abundance and extent of macropores and their influence in the movement of water and agricultural chemicals need further investigation;

2. Field measurement on the amount and rate of infiltration relevant to its efficiency in moving a pulse of chemical contaminant during and after precipitation is advocated;

3. Provision of more observation points in the soil profile, preferably in the mid-section of the soil layers, and at several sites in a field will provide one to be in a better position in describing the water and chemical movement in the profile.

4. Further investigation to confirm or deny the possibility of higher pollution potential risk of fields with subsurface drainage is suggested.

5. A shallow water table option be incorporated and linked with the Pesticide Component to expand the utilization of the GLEAMS model in areas susceptible to shallow water table formation.

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APPENDIX A

OBSERVED DAILY WATER TABLE AND RAINFALL

Table A.1. Observed daily water table depth and rainfall in the research area in 1991.

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
1	-88.04	-112.46	-95.14	-44.49	-79.56	0.5
2	-88.55	-112.28	-95.59	-40.32	-72.48	3.3
3	-70.51	-112.14	-73.58	-38.86	-50.34	6.3
4	-76.98	-112.02	-78.79	-37.47	-49.66	0
5	-78.98	-111.64	-82.36	-36.24	-49.39	0
6	-29.72	-91.51	-26.79	-22.04	-14.07	16.8
7	-62.21	-88.09	-48.52	-19.01	-11.57	0
8	-74.91	-89.91	-63.55	-23.49	-18.01	0.3
9	-78.41	-89.32	-72.00	-26.26	-25.96	0.8
10	-3.87	-3.34	-1.51	-3.74	-1.86	82.5
11	-23.69	-20.04	-5.66	-6.38	-3.27	0.5
12	-62.28	-62.64	-39.58	-14.49	-6.03	0
13	-75.23	-80.11	-62.21	-17.09	-8.85	0
14	-77.06	-83.15	-70.29	-20.87	-10.21	0
15	-68.06	-73.65	-51.88	-20.95	-13.67	10.3
16	-78.20	-85.21	-69.36	-21.14	-21.37	0
17	-81.31	-90.01	-78.12	-28.92	-29.93	0.8
18	-35.59	-52.02	-31.97	-24.99	-9.68	12.5
19	-69.58	-75.6	-49.83	-17.62	-13.03	0
20	-77.01	-84.43	-69.51	-23.67	-19.42	0
21	-80.85	-90.5	-78.71	-28.84	-24.86	0
22	-81.86	-93.01	-81.84	-33.25	-33.68	0
23	-29.61	-37.42	-24.82	-28.83	-12.28	18
24	-31.53	-22.47	-6.42	-15.48	-1.82	17.8
25	-60.46	-69.82	-39.77	-15.99	-6.03	0
26	-72.05	-84.03	-59.41	-16.61	-9.82	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
27	-33.62	-62.82	-25.72	-16.26	-1.93	12.5
28	-66.71	-80.04	-46.72	-15.78	-2.44	0
29	-41.11	-59.35	-34.58	-15.19	-0.06	8.3
30	-50.11	-63.41	-39.76	-14.48	-5.38	9.0
31	-72.04	-88.15	-58.92	-18.14	-7.56	0
32	-79.31	-92.05	-69.78	-21.75	-9.62	0
33	-79.96	-92.87	-77.56	-28.48	-15.34	0
34	-80.45	-93.66	-78.43	-29.67	-18.73	0
35	-80.93	-94.82	-79.12	-32.88	-22.29	1.3
36	-26.92	-42.14	-4.59	-14.47	-1.9	45.0
37	-62.51	-72.82	-41.57	-14.88	-8.66	0
38	-73.55	-84.63	-62.69	-18.76	-16.75	0
39	-77.61	-89.84	-72.5	-27.04	-22.53	0
40	-79.47	-95.97	-74.68	-30.14	-34.33	0
41	-81.36	-96.48	-76.03	-36.12	-37.82	0
42	-82.01	-96.96	-78.56	-36.89	-39.04	0
43	-82.41	-97.62	-80.12	-37.58	-38.49	0
44	-84.06	-98.14	-81.51	-38.14	-39.12	0
45	-84.51	-99.14	-87.46	-39.04	-40.52	0
46	-87.27	-101.17	-87.78	-40.57	-44.45	0
47	-85.98	-99.64	-88.36	-41.66	-47.37	0.8
48	-83.61	-97.22	-88.63	-42.97	-46.61	0
49	-83.41	-97.47	-88.95	-43.65	-47.11	0
50	-76.38	-90.77	-80.68	-31.38	-34.79	19.0
51	-6.64	-15.73	-1.23	-14.51	-3.66	46.3
52	-5.97	-5.72	-1.64	-16.91	-1.54	42.3
53	-31.67	-43.5	-27.82	-18.22	-5.86	0
54	-69.45	-83.67	-61.87	-23.53	-9.33	0
55	-75.71	-89.79	-70.13	-28.35	-15.84	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
56	-77.93	-91.64	-77.58	-34.39	-18.31	0
57	-79.65	-94.18	-84.7	-37.17	-21.03	0
58	-82.03	-95.46	-86.16	-38.82	-24.97	0
59	-82.54	-96.48	-86.54	-40.14	-28.46	0
60	-7.45	-26.03	-3.38	-35.76	-0.84	44.8
61	-6.41	-15.34	-3.05	-16.61	-0.56	50.0
62	-27.12	-39.8	-47.77	-18.54	-3.42	0
63	-69.71	-83.59	-66.48	-22.19	-8.63	0
64	-77.99	-91.96	-76.19	-25.73	-16.87	0
65	-80.33	-94.06	-81.13	-29.38	-22.21	0
66	-79.77	-95.63	-85.48	-33.59	-28.71	0
67	-83.68	-95.97	-89.51	-35.12	-35.66	0
68	-82.51	-96.41	-91.76	-36.92	-39.17	0
69	-85.12	-96.89	-92.24	-38.11	-40.68	0
70	-82.98	-97.28	-92.08	-38.87	-42.82	0
71	-80.69	-97.99	-91.99	-40.05	-44.5	0
72	-81.53	-98.12	-92.77	-41.36	-45.98	0
73	-82.69	-98.01	-93.46	-42.09	-47.76	0
74	-85.57	-97.93	-95.01	-52.64	-57.22	2.8
75	-52.71	-21.98	-33.85	-32.97	-1.02	33.0
76	-51.21	-67.28	-48.47	-25.34	-0.63	3.5
77	-76.78	-87.79	-78.08	-15.88	-6.85	1.3
78	-79.88	-91.78	-83.12	-16.63	-11.99	0
79	-80.78	-92.67	-85.41	-18.97	-17.34	0
80	-81.09	-93.79	-87.88	-20.53	-23.73	0
81	-81.55	-96.46	-88.34	-24.37	-27.95	0
82	-84.43	-96.63	-88.97	-27.05	-31.26	0
83	-87.36	-96.85	-89.53	-31.63	-33.86	0
84	-90.48	-97.02	-90.02	-33.02	-36.23	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
85	-91.61	-97.36	-90.75	-34.83	-37.81	0
86	-96.32	-97.78	-91.13	-36.09	-39.24	0
87	-98.46	-98.04	-92.56	-40.26	-40.38	0
88	-110.91	-100.37	-93.24	-41.03	-47.91	8.3
89	-120.34	-103.28	-95.01	-44.65	-56.21	0
90	-119.93	-103.86	-97.36	-52.48	-58.31	0
91	-118.85	-105.65	-98.73	-55.37	-59.42	0
92	-117.56	-107.23	-100.22	-59.25	-61.04	0
93	-117.03	-109.46	-103.45	-60.93	-62.89	0
94	-116.72	-110.13	-106.29	-62.31	-64.67	0
95	-116.38	-111.88	-108.64	-63.58	-66.9	0
96	-112.18	-112.78	-110.12	-64.05	-68.06	1.0
97	-111.96	-112.82	-111.37	-62.29	-70.82	10.0
98	-111.34	-112.96	-112.26	-63.84	-71.43	0
99	-110.66	-113.01	-113.11	-64.76	-72.16	0
100	-110.41	-113.24	-114.63	-65.6	-74.21	2.5
101	-109.38	-113.36	-115.78	-69.38	-75.06	0.3
102	-108.41	-113.42	-116.23	-70.53	-75.99	0
103	-107.56	-113.49	-116.84	-71.16	-76.82	0
104	-26.69	-39.93	-15.41	-8.18	-32.08	41.8
105	-66.41	-86.24	-32.67	-17.99	-14.08	0
106	-80.81	-92.1	-71.28	-20.76	-20.28	1
107	-83.26	-89.78	-70.31	-8.82	-17.08	7.3
108	-19.39	-42.68	-7.19	-5.28	-5.22	27.8
109	-45.72	-69.13	-47.37	-7.92	-3.25	8
110	-86.18	-76.36	-69.96	-10.04	-8.53	0
111	-86.72	-87.98	-75.16	-13.65	-13.41	0
112	-87.28	-93.27	-79.48	-15.28	-19.88	0
113	-87.67	-96.11	-82.03	-18.66	-26.85	3

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
114	-88.03	-96.98	-84.29	-22.48	-33.34	0.5
115	-88.46	-97.81	-86.58	-18.17	-37.49	7.5
116	-38.15	-47.27	-23.21	-8.8	-8.98	22.0
117	-75.88	-89.48	-69.92	-8.78	-13.09	0
118	-31.05	-46.46	-12.74	-8.75	-13.78	22.3
119	-13.55	-9.94	-6.09	-8.41	-14.46	75.0
120	-55.36	-81.68	-54.15	-8.26	-15.71	0.5
121	-80.84	-90.37	-66.79	-8.03	-26.31	0
122	-16.97	-10.06	-4.85	-8.33	-22.2	30.3
123	-64.61	-76.86	-42.51	-8.56	-23.7	0
124	-76.19	-42.35	-43.59	-8.79	-23.22	31.0
125	-78.83	-83.61	-71.21	-9.63	-25.93	0.5
126	-79.42	-91.17	-74.57	-19.03	-29.68	0
127	-80.69	-92.83	-77.58	-19.37	-34.74	1.5
128	-10.98	-12.41	-2.86	-2.48	-19.02	115.5
129	-10.74	-12	-5.73	-0.16	-12.15	27.0
130	-12.93	-44.89	-32.83	-2.68	-8.09	34.8
131	-64.48	-72.81	-64.27	-4.98	-16.09	0
132	-75.19	-85.49	-68.58	-7.41	-22.43	0
133	-75.01	-88.36	-74.03	-9.67	-26.25	0
134	-52.84	-90.41	-76.21	-15.27	-27.02	0.3
135	-49.32	-79.42	-63.64	-5.58	-22.71	21.5
136	-66.55	-89.57	-73.8	-11.79	-27.42	0
137	-10.31	-47.42	-30.61	-3.15	-29.78	22.5
138	-40.61	-69.71	-51.45	-5.25	-28.04	11.8
139	-64.68	-77.67	-64.79	-4.24	-25.76	5.5
140	-21.71	-37.22	-19.87	-4.31	-23.32	12.5
141	-60.91	-83.04	-63.41	-4.35	-21.55	3.5
142	-69.89	-88.44	-73.63	-4.44	-23.17	0.3

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
143	-73.59	-88.94	-70.62	-3.62	-22.3	3.5
144	-74.68	-89.37	-75.23	-7.42	-26.86	0.3
145	-49.74	-77.95	-53.56	-8.92	-22.37	9.8
146	-72.58	-82.56	-68.33	-9.69	-26.28	0
147	-73.68	-89.89	-72.37	-8.33	-30.92	3.3
148	-74.24	-90.67	-74.81	-16.45	-34.65	0
149	-74.85	-91.89	-76.72	-21.25	-37.98	0.8
150	-76.99	-93.31	-78.04	-19.28	-42.04	6.8
151	-78.83	-93.81	-79.87	-25.59	-45.83	0
152	-68.09	-94.26	-80.56	-29.74	-48.02	0
153	-59.94	-94.79	-81.34	-31.68	-49.45	0
154	-52.45	-94.98	-82.03	-33.91	-50.63	0
155	-50.59	-95.09	-83.3	-35.25	-52.36	0
156	-41.22	-61.7	-17.77	-15.98	-17.56	50.0
157	-11.1	-56.39	-43.55	-15.29	-20.15	45.3
158	-27.16	-86.23	-65.82	-15.76	-31.67	0
159	-42.29	-88.16	-73.34	-16.28	-39.44	0
160	-32.38	-90.54	-77.26	-20.37	-40.94	0
161	-22.19	-93.28	-81.17	-17.83	-46.98	6.5
162	-39.29	-71.39	-64.41	-15.55	-43.03	21.8
163	-57.51	-78.71	-66.33	-14.56	-38.06	6.0
164	-70.05	-89.38	-71.42	-14.92	-35.39	0.8
165	-74.03	-91.26	-77.85	-15.33	-39.07	0
166	-76.01	-92.85	-79.09	-17.21	-43.85	0
167	-64.16	-93.47	-81.36	-18.97	-44.32	0
168	-45.49	-94.18	-83.61	-22.12	-45.71	6.0
169	-61.22	-77.89	-42.86	-16.62	-43.99	51.8
170	-75.08	-88.47	-73.56	-14.76	-42.18	0
171	-73.58	-91.79	-76.14	-17.29	-40.52	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
72	-72.36	-93.43	-78.87	-21.07	-41.96	0
173	-71.48	-94.98	-81.35	-22.09	-45.54	5.3
174	-70.18	-96	-83.29	-23.13	-48.17	0
175	-69.83	-97.74	-63.94	-7.72	-42.45	15.8
176	-76.63	-94.56	-74.84	-12.98	-40.36	0
177	-75.54	-94.44	-80.13	-17.51	-41.19	0
178	-76.69	-96.31	-83.06	-14.29	-41.55	5.8
179	-74.31	-97.24	-85.31	-20.87	-42.96	0
180	-72.26	-97.42	-85.67	-21.99	-44.55	0.3
181	-68.44	-97.76	-86.01	-22.86	-45.33	0
182	-63.71	-98.02	-86.42	-22.47	-44.64	0
183	-56.77	-98.16	-87.09	-21.63	-45.26	4.3
184	-47.09	-96.64	-87.63	-21.04	-45.91	0
185	-50.04	-74.27	-45.42	-4.16	-39.39	55.3
186	-67.81	-83.12	-68.78	-6.28	-38.59	4.5
187	-39.52	-54.28	-38.94	-3.31	-38.02	23.5
188	-43.15	-51.04	-42.67	-3.26	-36.86	27.3
189	-67.94	-84.05	-70.93	-3.18	-36.13	1.8
190	-64.78	-86	-62.65	-3.96	-35.71	5.3
191	-70.99	-89.08	-75.83	-5.3	-35.7	0
192	-72.49	-91.13	-76.19	-11.24	-35.27	0
193	-76.07	-91.56	-76.48	-12.41	-36.07	0
194	-76.58	-91.94	-76.87	-14.06	-36.98	0
195	-77.34	-92.35	-77.32	-15.66	-37.48	0
196	-77.95	-92.77	-78.03	-16.47	-38.26	0
197	-78.22	-93.42	-78.87	-17.25	-38.96	0
198	-78.63	-93.83	-79.41	-19.34	-39.57	0
199	-79.05	-94.44	-80.04	-21.43	-40.01	0
200	-79.93	-95.23	-80.76	-22.51	-42.03	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
201	-80.36	-96.02	-81.36	-24.84	-43.67	0
202	-80.98	-96.91	-82.52	-31.07	-44.23	0
203	-81.52	-97.65	-83.87	-35.49	-46.78	0
204	-81.99	-98.06	-84.29	-36.56	-49.79	0.3
205	-82.37	-98.77	-84.96	-37.69	-50.48	0
206	-84.53	-99.04	-85.87	-38.93	-51.36	0
207	-85.01	-100.56	-86.63	-39.77	-53.01	12.5
208	-87.35	-101.47	-87.24	-41.32	-53.65	0.3
209	-89.46	-102.25	-89.02	-42.61	-54.27	0
210	-91.63	-103.67	-89.99	-44.18	-55.15	0
211	-93.77	-104.04	-90.93	-45.03	-55.88	0
212	-97.98	-106.68	-91.86	-46.97	-57.12	0
213	-101.42	-108.26	-92.23	-48.12	-57.96	0
214	-105.67	-110.81	-92.85	-49.01	-58.56	0
215	-109.89	-111.79	-100.11	-52.44	-59.03	0
216	-112.62	-112.51	-103.07	-55.92	-59.87	0
217	-116.13	-113.67	-105.02	-58.86	-60.64	0
218	-118.93	-114.83	-107.46	-59.31	-61.06	0
219	-120.61	-116.03	-108.52	-61.46	-61.99	1.3
220	-121.81	-116.64	-115.98	-63.74	-62.77	2.3
221	-126.59	-116.71	-124.41	-65.08	-63.06	0.3
222	-126.92	-116.78	-125.06	-66.94	-63.81	14.0
223	-127.24	-116.89	-125.84	-67.56	-65.18	0.3
224	-127.67	-117.01	-126.87	-68.11	-66.02	0
225	-128.03	-117.18	-127.66	-69.05	-67.13	0
226	-128.74	-117.24	-127.73	-69.93	-68.85	2.3
227	-129.23	-117.31	-127.91	-70.66	-69.54	0
228	-129.61	-117.33	-127.99	-71.27	-71.69	0
229	-130.17	-117.46	-128.18	-72.03	-72.17	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
230	-130.86	-117.5	-128.41	-72.87	-72.86	0
231	-131.18	-117.53	-128.56	-73.45	-73.28	0
232	-131.92	-117.56	-128.69	-74.01	-73.99	0
233	-132.78	-117.61	-128.82	-74.98	-74.47	0
234	-133.15	-117.63	-128.82	-76.31	-75.36	0
235	-133.63	-117.77	-128.82	-77.85	-76.04	0
236	-133.98	-117.92	-128.81	-78.93	-76.81	0
237	-134.56	-118.19	-128.81	-80.27	-77.58	0
238	-135.18	-118.41	-128.81	-82.01	-78.45	0
239	-130.12	-118.78	-128.8	-11.59	-52.18	48.5
240	-119.18	-118.94	-128.81	-19.78	-41.46	0.5
241	-85.12	-119.18	-128.81	-24.17	-30.77	0
242	-70.69	-85.71	-43.22	-9.75	-26.9	50.0
243	-106.01	-116.87	-94.56	-10.75	-19.35	2.3
244	-116.01	-119.98	-106.7	-13.74	-19.65	0.3
245	-105.28	-108.38	-97.84	-9.61	-19.98	13.5
246	-113.62	-117.72	-107.11	-14.08	-20.15	0
247	-118.34	-117.77	-112.72	-16	-24.85	0.5
248	-122.63	-117.84	-115.22	-19.65	-27.07	4.5
249	-125.14	-117.86	-119.04	-24.12	-29.51	0.3
250	-112.06	-117.98	-115.23	-16.04	-24.06	11.3
251	-117.44	-118.06	-115.98	-13.07	-25.43	0
252	-126.39	-118.32	-116.71	-19.26	-26.88	1.3
253	-132.52	-118.63	-121.59	-21.63	-28.13	0
254	-135.11	-118.85	-124.09	-24.57	-29.98	0
255	-135.16	-119.01	-124.85	-27.86	-32.04	0
256	-135.18	-119.25	-125.36	-30.42	-33.87	0
257	-135.42	-119.42	-126.03	-33.17	-35.01	0
258	-135.66	-119.63	-126.78	-35.97	-36.67	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
259	-135.93	-119.92	-127.01	-41.86	-37.78	0
260	-136.12	-120.12	-127.4	-45.14	-39.02	0.3
261	-136.25	-120.21	-128.18	-49.76	-40.93	0
262	-136.31	-120.22	-128.17	-54.78	-42.01	6.3
263	-136.38	-120.24	-128.14	-59.17	-43.48	0
264	-135.49	-120.26	-128.12	-64.24	-45.09	0
265	-136.15	-120.28	-128.08	-68.39	-46.76	0
266	-135.88	-120.29	-128.05	-59.28	-47.23	18.0
267	-135.65	-120.3	-128.02	-53.76	-49.86	8.5
268	-135.42	-120.31	-127.99	-51.29	-50.65	0.8
269	-135.29	-120.32	-127.95	-56.35	-51.99	0
270	-135.26	-120.33	-127.93	-61.14	-52.86	0
271	-135.18	-120.34	-127.88	-62.47	-54.18	0
272	-138.28	-120.36	-127.86	-63.21	-55.29	0
273	-135.31	-120.42	-127.83	-64.68	-56.34	0
274	-135.36	-120.46	-127.77	-65.26	-57.03	0
275	-135.48	-120.5	-127.73	-67.38	-58.52	0
276	-135.51	-120.48	-127.96	-69.02	-59.38	0
277	-135.56	-120.45	-128.21	-70.65	-61.69	0.5
278	-135.61	-120.44	-128.35	-72.05	-63.24	0
279	-135.65	-120.41	-128.41	-74.97	-65.04	0
280	-135.67	-120.35	-128.44	-76.43	-66.99	0
281	-135.73	-120.35	-128.53	-78.16	-67.28	0
282	-135.97	-120.33	-128.58	-81.93	-67.93	0
283	-136.05	-120.32	-128.62	-83.06	-68.42	0
284	-136.48	-120.31	-128.66	-84.27	-69.13	0
285	-135.02	-120.3	-128.69	-86.02	-70.01	0
286	-135	-120.28	-128.72	-87.86	-70.87	0
287	-135.02	-120.26	-128.84	-89.13	-71.46	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
288	-135.04	-120.24	-129.96	-90.38	-72.11	0
289	-135.06	-120.23	-129.21	-91.81	-72.75	0
290	-135.07	-120.21	-129.43	-92.36	-73.24	0
291	-135.08	-120.19	-129.65	-92.59	-73.91	0
292	-135.13	-120.24	-129.69	-94.88	-74.45	0
293	-135.18	-120.28	-129.74	-96.16	-75.67	0
294	-135.11	-120.29	-129.78	-97.31	-76.38	0
295	-135.03	-120.33	-129.81	-87.92	-72.89	18.3
296	-134.98	-120.36	-129.86	-66.23	-56.44	11.8
297	-134.92	-120.43	-129.43	-72.78	-47.16	0
298	-134.87	-120.51	-129.25	-79.03	-44.88	0
299	-115.89	-120.68	-115.6	-2.11	-5.28	56.5
300	-92.84	-120.85	-122.78	-3.45	-6.46	3.5
301	-114.51	-120.96	-123.13	-5.03	-7.27	1.0
302	-134.34	-121.04	-123.49	-6.42	-12.16	1.5
303	-135.29	-121.12	-124.18	-3.9	-10.29	3.3
304	-122.4	-121.01	-124.96	-4.84	-2.57	7.5
305	-111.39	-120.98	-126.03	-12.02	-9.27	3.3
306	-113.42	-120.89	-127.97	-21.21	-23.86	0
307	-116.46	-120.76	-127.49	-39.56	-32.57	0
308	-123.32	-120.49	-128.21	-36.21	-44.76	0
309	-125.27	-120.31	-128.43	-41.35	-48.03	0
310	-126.03	-120.18	-128.57	-43.66	-49.38	0
311	-126.84	-120.03	-128.68	-46.73	-52.65	2.5
312	-127.42	-119.96	-128.77	-48.04	-54.13	3.5
313	-128.98	-119.88	-128.89	-50.28	-55.61	0
314	-129.16	-119.84	-128.06	-51.23	-56.34	0
315	-129.33	-119.76	-127.33	-56.75	-58.12	0
316	-129.81	-119.71	-127.18	-60.08	-62.16	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
317	-130.26	-119.68	-127.01	-63.28	-64.86	0
318	-130.51	-119.66	-126.74	-65.02	-66.74	0
319	-130.53	-119.62	-126.41	-66.16	-68.01	0
320	-130.5	-119.56	-126.27	-66.97	-68.28	0
321	-130.46	-119.47	-126.12	-67.49	-68.49	0
322	-130.44	-119.41	-125.93	-68.01	-68.84	0
323	-130.43	-119.38	-125.71	-56.06	-65.37	7.8
324	-58.96	-119.34	-78.09	-12.49	-39.41	24.0
325	-79.37	-119.33	-84.93	-12.59	-36.75	0.8
326	-89.57	-119.29	-95.53	-13.51	-36.29	0.3
327	-92.18	-119.27	-96.18	-19.63	-41.38	0
328	-95.16	-119.26	-97.04	-28.81	-47.67	0
329	-97.59	-119.24	-98.67	-34.75	-50.49	0
330	-97.86	-119.18	-100.37	-39.79	-53.94	0
331	-98.41	-119.15	-102.48	-40.04	-54.36	0
332	-98.64	-119.11	-104.02	-40.97	-55.22	0
333	-99.03	-119.08	-106.35	-41.36	-56.29	1.5
334	-99.65	-119.05	-107.86	-42.56	-57.02	0
335	-97.68	-119.01	-106.98	-43.14	-50.84	7.3
336	-72.86	-118.99	-93.68	-42.87	-46.67	8.8
337	-84.05	-118.43	-97.15	-39.03	-46.57	0
338	-87.98	-117.24	-98.96	-37.97	-50.64	0
339	-88.53	-116.09	-100.41	-37.02	-52.58	0
340	-89.02	-115.57	-101.23	-36.18	-53.63	0
341	-89.93	-114.97	-101.86	-34.47	-53.68	0
342	-92.72	-114.66	-102.47	-43.52	-53.77	0.3
343	-75.02	-106.21	-77.16	-20.27	-50.13	13.0
344	-81.18	-97.72	-83.51	-20.63	-38.12	0
345	-82.59	-100.44	-87.03	-21.17	-40.56	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
346	-82.69	-101.32	-91.94	-21.96	-40.19	0
347	-64.2	-79.59	-58.46	-16.54	-38.94	11.5
348	-74.89	-97.04	-73.26	-18.04	-36.04	1.5
349	-80.25	-98.28	-83.2	-19.87	-37.21	0
350	-82.15	-98.47	-87.73	-20.96	-41.05	0
351	-83.86	-98.73	-89.25	-22.45	-43.96	0
352	-86.93	-101.77	-91.5	-24.03	-49.52	0
353	-86.31	-103.56	-92.04	-25.38	-50.18	0
354	-86.18	-104.14	-92.38	-26.97	-50.96	0
355	-85.97	-104.21	-93.16	-37.38	-49.33	0
356	-84.76	-104.57	-93.98	-37.06	-47.62	0.5
357	-83.67	-104.96	-94.31	-38.87	-49.11	5
358	-86.64	-106.43	-94.87	-39.96	-51.3	0
359	-87.48	-105.89	-95.22	-40.74	-56.29	0
360	-88.21	-106.55	-96.03	-43.48	-56.81	0
361	-88.79	-107.05	-96.29	-46.01	-57.35	4.5
362	-89.86	-107.79	-96.58	-49.92	-59.22	0
363	-90.54	-108.95	-99.04	-52.35	-62.35	0
364	-90.86	-110.14	-99.87	-57.74	-65.38	0
365	-91.53	-112.03	-99.66	-60.34	-66.86	0

Table A.2. Observed daily water table depths and rainfall in the research area in 1992.

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
1	-90.71	-109.42	-99.78	-58.75	-67.09	0
2	-91.07	-109.64	-99.85	-58.72	-67.07	0
3	-91.45	-109.87	-99.93	-59.04	-67.05	0
4	-91.76	-110.14	-99.97	-59.66	-67.02	0
5	-92.01	-110.52	-100.08	-59.97	-66.09	0
6	-92.16	-110.98	-100.17	-60.58	-66.97	0
7	-94.37	-111.52	-100.23	-61.26	-66.7	0
8	-6.44	-23.35	-10.73	-44.01	-48.42	69.8
9	-66.56	-83.02	-58.99	-5.79	-24.19	0.3
10	-71.83	-87.61	-67.14	-7.26	-24.24	0
11	-77.31	-93.13	-81.07	-7.29	-27.74	0
12	-38.03	-54.64	-31.25	-3.44	-14.54	29.3
13	-73.95	-91.84	-58.72	-3.09	-15.88	0.1
14	-79.22	-95.18	-69.08	-5.86	-26.7	0
15	-82.13	-95.76	-81.29	-8.39	-37.69	0
16	-82.14	-96.64	-85.67	-11.93	-40.49	0
17	-82.15	-98.3	-90.12	-8.77	-41.71	1.5
18	-11.03	-31.74	-6.6	-6.36	-20.89	77.5
19	-63.01	-86.1	-58.35	-7.17	-31.34	0
20	-68.46	-88.54	-65.51	-6.28	-30.84	0
21	-75.12	-92.35	-77.79	-5.37	-30.3	0
22	-6.75	-24.86	-9.98	-3.23	-10.37	39.5
23	-62.05	-75.45	-66.59	-4.55	-22.87	0
24	-65.96	-91.54	-71.92	-5.46	-24.38	0
25	-72.43	-93.83	-77.35	-6.58	-27.69	0
26	-77.48	-94.46	-83.41	-7.48	-28.88	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
27	-5.13	-24.11	-3.83	-1.8	-8.44	42.0
28	-58.59	-43.81	-54.44	-2.18	-8.81	32.3
29	-51.69	-27.31	-55.39	-2.41	-5.62	0.8
30	-70.38	-52.25	-67.24	-2.96	-3.01	0
31	-72.18	-63.42	-78.73	-4.25	-5.64	0
32	-74.46	-76.46	-79.98	-5.18	-10.07	0
33	-77.03	-82.91	-82.67	-6.96	-17.09	0
34	-78.23	-89.74	-85.94	-8.79	-20.94	0
35	-5.81	-22.36	-3.87	-0.87	-3.42	67.8
36	-53.66	-78.92	-57.74	-8.7	-7.34	3.3
37	-65.46	-89.99	-75.48	-9.09	-11.66	0
38	-67.08	-95.02	-85.09	-9.86	-15.73	0
39	-69.34	-95.41	-86.81	-10.27	-25.59	0
40	-71.85	-95.78	-88.26	-11.13	-34.49	0
41	-74.13	-96.03	-89.95	-12.01	-35.36	0
42	-77.26	-96.48	-91.18	-13.42	-36.63	0
43	-79.62	-96.82	-93.03	-14.96	-37.99	0.8
44	-14.34	-20.86	-16.23	-3.11	-13.9	25.3
45	-25.28	-39.98	-10.19	-4.43	-0.52	26.3
46	-41.59	-66.62	-40.35	-2.96	-5.79	62.5
47	-51.34	-68.15	-23.98	-3.84	-4.51	7.0
48	-62.07	-80.54	-55.81	-4.99	-4.32	18.5
49	-68.49	-86.48	-82.71	-6.89	-9.48	0
50	-78.16	-93.67	-87.54	-8.53	-16.63	0
51	-78.93	-95.33	-88.26	-12.1	-23.04	0
52	-79.6	-97.69	-88.17	-13.24	-25.87	0
53	-53.28	-74.21	-36.27	-10.04	-19.46	16.0
54	-75.33	-81.69	-75.35	-5.36	-13.98	0
55	-76.01	-93.01	-85.5	-1.89	-11.05	0.5

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
56	-76.99	-93.87	-87.66	-2.28	-14.04	0.5
57	-77.34	-94.48	-89.23	-4.09	-22.33	0
58	-78.92	-95.23	-89.68	-5.55	-26.33	0
59	-79.96	-96.49	-90.01	-8.62	-34.64	0
60	-81.46	-97.38	-90.43	-15.13	-37.32	0
61	-82.22	-98.87	-90.82	-17.18	-39.98	0
62	-82.03	-99.05	-91.38	-18.96	-41.19	0
63	-81.96	-99.93	-91.86	-21.02	-40.56	0
64	-81.88	-100.41	-92.31	-23.73	-40.08	0
65	-5.17	-23.97	-5.26	-3.05	-7.25	68.8
66	-65.06	-80.81	-67.33	-4.91	-10.38	0
67	-73.69	-91.67	-79.98	-6.18	-11.43	0
68	-77.21	-92.89	-86.62	-9.67	-12.21	0
69	-63.27	-94.57	-71.57	-8.16	-11.36	5.8
70	-72.44	-84.73	-76.39	-12.49	-22.91	3.8
71	-74.95	-94.95	-85.15	-16.87	-26.89	0
72	-76.78	-97.61	-89.87	-20.42	-35.61	0
73	-78.21	-98.02	-90.26	-24.91	-38.96	0
74	-79.94	-98.83	-90.99	-29.14	-43.72	0
75	-81.54	-99.76	-92.48	-33.51	-47.44	0
76	-81.86	-100.61	-93.18	-35.27	-48.77	0
77	-82.07	-101.26	-93.82	-38.85	-48.32	0.3
78	-62.28	-80.52	-48.59	-8.82	-29.18	20.0
79	-77.59	-94.21	-83.11	-10.62	-28.59	0
80	-77.83	-96.45	-85.67	-19.93	-31.01	0
81	-78.17	-97.86	-87.52	-16.44	-32.58	2.3
82	-58.93	-80.52	-76.88	-7.85	-27.42	7.8
83	-61.38	-84.96	-84.96	-10.06	-31.27	0
84	-66.67	-92.05	-85.83	-15.94	-32.88	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
85	-73.81	-98.08	-87.64	-18.47	-34.79	1.0
86	-79.22	-98.31	-89.56	-23.81	-38.78	0
87	-80.92	-98.97	-92.44	-26.62	-41.5	0
88	-78.83	-99.03	-91.03	-31.26	-42.09	4.8
89	-77.21	-99.78	-89.57	-20.49	-40.99	5.8
90	-79.26	-100.13	-90.16	-22.53	-45.11	0
91	-79.93	-100.66	-90.91	-25.94	-47.36	0
92	-80.68	-101.09	-91.87	-28.68	-49.88	0
93	-81.46	-101.83	-93.21	-33.2	-52.61	0
94	-81.23	-102.26	-94.08	-40.09	-54.62	0
95	-81.05	-102.93	-95.21	-45.61	-55.11	0
96	-79.35	-103.32	-93.06	-44.92	-56	2.5
97	-78.83	-104.69	-92.81	-33.01	-49.51	12.0
98	-78.01	-103.86	-92.35	-34.45	-53.55	0
99	-77.12	-102.41	-91.78	-36.03	-53.98	0
100	-80.95	-101.36	-91.03	-37.32	-54.55	0
101	-80.35	-101.77	-92.34	-39.67	-55.04	4.5
102	-81.43	-102.38	-94.86	-43.69	-58.1	0
103	-82.76	-102.96	-96.19	-48.33	-59.84	0
104	-5.32	-28.31	-15.33	-9.77	-32.2	34.8
105	-62.33	-25.12	-75.72	-11.98	-32.03	0
106	-69.42	-86.05	-84.49	-14.11	-31.81	0
107	-77.81	-95.58	-87.44	-18.31	-31.75	1.3
108	-78.99	-95.97	-86.83	-13.03	-31.56	4.8
109	-79.43	-96.23	-86.98	-13.41	-31.48	1.5
110	-79.97	-97.02	-87.21	-13.65	-32.55	0
111	-80.26	-97.89	-87.58	-17.98	-40.51	3.5
112	-80.72	-98.21	-87.92	-22.99	-44.07	0
113	-81.93	-98.86	-88.63	-27.43	-48.53	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
114	-83.02	-99.1	-89.26	-34.01	-49.27	1.0
115	-80.24	-99.68	-91.67	-38.91	-50.09	4.3
116	-80.72	-100.03	-92.56	-39.43	-54.12	8.0
117	-81.03	-100.57	-93.21	-40.67	-56.93	0
118	-81.54	-100.98	-94.35	-41.31	-59.66	0
119	-82.93	-101.33	-95.03	-45.16	-60.73	0
120	-84.19	-101.89	-95.84	-50.39	-61.99	3.3
121	-83.38	-102.06	-95.18	-53.2	-64.79	0
122	-83.42	-102.58	-95.39	-53.31	-64.58	0
123	-83.56	-102.97	-95.73	-53.99	-63.74	0
124	-83.6	-103.18	-95.91	-54.38	-63.16	0
125	-83.65	-103.41	-96.16	-54.87	-62.68	0
126	-83.72	-103.98	-96.32	-55.41	-62.12	1.8
127	-83.77	-104.16	-96.69	-57.13	-64.89	0
128	-83.99	-104.43	-96.95	-58.85	-66.99	0
129	-84.13	-104.73	-97.13	-59.27	-67.18	0
130	-84.26	-105.02	-97.41	-59.91	-67.41	0
131	-84.52	-105.28	-97.86	-60.49	-67.87	0
132	-84.73	-105.41	-98.12	-61.05	-68.41	0
133	-84.91	-105.53	-98.59	-61.42	-68.92	3.0
134	-85.04	-105.59	-98.97	-61.97	-69.68	0
135	-84.09	-105.66	-99.03	-62.84	-69.14	0
136	-85.16	-105.71	-99.39	-63.55	-69.21	0
137	-85.23	-106.15	-99.81	-64.93	-69.29	3.5
138	-85.36	-107.12	-99.85	-65.43	-71.35	0.3
139	-85.44	-108.35	-99.89	-66.37	-71.97	0.3
140	-85.49	-109.8	-99.92	-67.28	-72.46	0
141	-85.57	-109.89	-99.93	-68.44	-73.05	0
142	-86.63	-109.98	-99.96	-68.82	-73.85	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
143	-87.36	-110.03	-99.97	-69.08	-74.43	0
144	-88.5	-110.12	-99.97	-69.63	-74.91	6.0
145	-88.48	-110.02	-99.98	-69.91	-75.28	0
146	-88.47	-109.96	-100	-70.19	-75.67	0
147	-80.36	-109.91	-95.96	-65.93	-73.1	21.3
148	-24.06	-108.37	-27.64	-21.89	-12.84	24.5
149	-55.97	-79.09	-68.75	-6.03	-4.7	8.8
150	-68.23	-88.59	-72.71	-8.93	-9.77	1.3
151	-74.01	-70.12	-76.42	-16.77	-16.23	0
152	-78.43	-90.21	-83.63	-18.95	-21.77	1.8
153	-78.89	-16.03	-87.41	-23.08	-25.26	1.0
154	-11.83	-42.64	-9.21	-7.41	-1.95	37.0
155	-50.38	-66.99	-32.12	-4.89	-2.08	8.3
156	-73.49	-85.22	-69.89	-8.51	-2.19	0.3
157	-77.54	-90.78	-74.96	-12.92	-8.38	0
158	-79.09	-93.58	-84.25	-19.86	-14.36	0.8
159	-61.06	-91.43	-60.12	-7.58	-8.23	20.8
160	-71.8	-90.77	-66.35	-9.11	-4.65	4.0
161	-75.38	-92.05	-74.58	-10.54	-6.55	0.5
162	-79.35	-93.58	-80.16	-11.96	-9.32	0
163	-62.46	-53.73	-31.24	-5.16	-3.23	22.5
164	-61.71	-69.02	-45.67	-5.04	-2.73	16.0
165	-52.43	-40.15	-19.22	-4.92	-2.46	12.0
166	-73.91	-78.14	-67.15	-10.11	-2.39	1.8
167	-75.83	-91.95	-83.33	-13.46	-6.94	0
168	-77.65	-93.48	-84.59	-16.05	-13.56	0
169	-78.21	-94.96	-86.21	-18	-18.81	3.8
170	-78.83	-96.71	-88.63	-19.96	-23.42	0.3
171	-79.18	-96.98	-89.92	-23.18	-24.35	5.5

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
172	-79.95	-97.19	-91.16	-26.51	-25.96	2.8
173	-79.99	-97.41	-91.63	-28.03	-28.07	0
174	-80.08	-97.73	-92.05	-29.88	-28.63	0
175	-80.21	-97.91	-92.72	-31.12	-29.19	0
176	-80.33	-98.08	-93.02	-33.26	-30.07	0
177	-80.46	-98.28	-93.44	-35.64	-31.06	0
178	-80.16	-98.93	-93.67	-41.67	-32.37	0.5
179	-79.93	-99.87	-93.91	-44.01	-33.96	0.3
180	-79.67	-100.58	-94.28	-47.51	-35.02	0
181	-79.46	-101.15	-94.72	-49.43	-36.39	0.5
182	-39.62	-52.23	-38.55	-4.93	-8.97	136.7
183	-68.85	-87.45	-77.28	-9.61	-18.71	0
184	-72.87	-93.14	-87.15	-14.36	-24.53	0
185	-77.16	-94.04	-88.49	-21.57	-25.23	0
186	-77.9	-94.73	-90.63	-25.84	-25.97	0
187	-77.98	-95.21	-92.32	-30.77	-26.45	0
188	-78.13	-95.96	-92.93	-33.18	-27.78	0
189	-78.33	-96.28	-93.41	-35.85	-32.86	0
190	-78.48	-96.81	-94.08	-38.54	-33.95	0
191	-78.69	-97.35	-94.79	-41.93	-36.04	0.5
192	-73.75	-88.22	-59.01	-29.04	-33.03	37.0
193	-74.06	-93.92	-68.34	-34.65	-27.84	0
194	-75.13	-94.25	-77.63	-36.94	-33.49	0
195	-76.01	-95.06	-88.76	-38.87	-33.39	0
196	-76.89	-96.13	-90.35	-40.86	-38.13	0
197	-78.93	-97.49	-92.01	-42.98	-41.63	1.0
198	-79.71	-98.75	-94.72	-49.42	-44.38	2.3
199	-80.24	-100.48	-95.36	-52.03	-49.68	1.5
200	-82.03	-103.19	-96.15	-53.98	-53.92	2.8

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
201	-83.97	-104.83	-97.05	-57.35	-57.46	0.3
202	-85.44	-105.56	-97.98	-60.87	-55.65	10.3
203	-86.09	-106.77	-98.82	-64.09	-52.71	1.5
204	-89.15	-108.46	-86.71	-43.24	-46.49	17.3
205	-43.32	-66.03	-43.49	-11.05	-30.75	62.0
206	-58.85	-73.87	-50.64	-7.29	-23.81	15.5
207	-67.81	-90.42	-62.31	-16.55	-25.42	0
208	-74.34	-95.56	-76.58	-19.83	-26.86	0.3
209	-80.14	-96.41	-88.67	-23.16	-28.93	0
210	-82.38	-97.76	-90.34	-27.41	-30.77	5.0
211	-84.19	-98.92	-92.86	-32.8	-33.61	0
212	-85.99	-101.27	-94.25	-36.38	-37.59	7.5
213	-89.81	-104.78	-96.62	-41.21	-41.88	1.3
214	-74.45	-91.41	-78.09	-33.95	-41.76	34.0
215	-76.92	-95.01	-84.63	-35.65	-41.62	0
216	-79.44	-98.74	-89.91	-36.38	-41.43	0
217	-82.36	-93.58	-97.05	-38.18	-46.43	0
218	-84.7	-106.35	-98.34	-40.86	-47.96	0.3
219	-92.45	-109.17	-99.97	-43.09	-49.09	0
220	-94.67	-113.03	-103.26	-50.48	-54.37	0.3
221	-96.33	-113.88	-105.69	-52.18	-61.02	0
222	-98.04	-114.38	-107.87	-53.98	-62.36	1.0
223	-99.86	-114.96	-111.24	-56.14	-63.98	0.5
224	-100.65	-115.49	-115.52	-58.23	-65.56	0
225	-102.35	-116.08	-118.23	-59.96	-67.38	3.3
226	-103.93	-116.94	-120.89	-61.37	-69.02	7.3
227	-115.09	-116.99	-121.28	-63.86	-70.73	1.5
228	-121.86	-117.27	-122.03	-65.21	-73.21	0
229	-126.37	-117.49	-122.96	-67.53	-75.3	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
230	-127.83	-117.63	-123.58	-69.35	-77.87	0
231	-129.42	-117.79	-124.63	-72.11	-79.41	0
232	-130.96	-117.97	-125.39	-74.85	-81.15	0
233	-130.97	-117.89	-127.52	-77.48	-88.76	0
234	-130.97	-117.83	-128.16	-79.67	-92.48	0
235	-130.97	-117.96	-127.93	-76.32	-87.87	18.3
236	-130.98	-118.05	-127.24	-69.5	-81.5	6.5
237	-130.98	-118.16	-126.81	-66.35	-85.33	4.0
238	-130.98	-118.24	-126.34	-63.88	-83.39	10.5
239	-12.68	-19.38	-20.66	-6.68	-15.29	56.3
240	-50.05	-60.37	-72.94	-18.27	-28.73	0
241	-74.8	-77.03	-94.05	-21.93	-42.71	0
242	-83.67	-88.75	-100.3	-26.66	-52.91	0
243	-93.41	-101.85	-102.58	-31.98	-64.28	0
244	-96.62	-104.26	-106.72	-38.65	-71.18	0
245	-98.18	-108.47	-109.31	-42.85	-77.7	0.3
246	-110.49	-110.65	-112.58	-48.61	-80.87	0
247	-118.6	-113.19	-123.73	-55.25	-85.48	11.3
248	-120.85	-115.35	-124.18	-58.13	-89.95	0
249	-126.41	-117.48	-125.84	-61.55	-93.29	0
250	-67.57	-92.03	-60.14	-32.21	-64.02	47.3
251	-53.99	-76.82	-65.41	-14.14	-34.61	21.5
252	-62.22	-98.49	-97.02	-18.03	-46.66	0
253	-74.71	-92.96	-103.63	-21.63	-56.77	0
254	-80.63	-109.27	-108.49	-24.98	-60.81	0
255	-84.38	-110.08	-113.96	-28.67	-65.96	0
256	-90.06	-110.93	-120.66	-33.22	-69.87	0
257	-85.13	-112.58	-121.58	-38.41	-73.58	0
258	-98.43	-113.23	-122.32	-42.96	-76.32	1.0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
259	-101.26	-115.41	-124.16	-47.18	-78.93	0
260	-103.94	-116.81	-125.94	-52.08	-80.56	0.3
261	-107.22	-117.03	-126.29	-56.82	-84.03	3.0
262	-110.86	-117.49	-126.83	-60.43	-88.35	0
263	-114.91	-117.58	-127.32	-61.56	-90.96	0
264	-118.17	-117.73	-127.38	-62.38	-93.42	0
265	-121.13	-117.81	-127.45	-63.16	-96.04	12.0
266	-124.33	-117.93	-127.46	-54.44	-98.63	0
267	-126.47	-118.02	-127.51	-65.97	-101.55	0
268	-126.83	-118.09	-127.52	-67.02	-103.93	0
269	-127.03	-118.14	-127.54	-67.96	-106.22	0
270	-127.41	-118.21	-127.58	-68.87	-108.89	0
271	-127.68	-118.24	-127.61	-70.09	-109.28	0
272	-127.87	-118.28	-127.63	-72.21	-109.76	0
273	-127.99	-118.31	-127.69	-72.81	-110.03	0
274	-128.16	-118.32	-127.74	-73.36	-110.77	0
275	-128.45	-118.33	-127.82	-74.89	-111.52	0
276	-128.06	-118.16	-127.93	-77.96	-113.23	0
277	-127.53	-118.07	-128.05	-79.16	-113.59	0
278	-127.01	-118	-128.09	-82.72	-113.92	0
279	-125.42	-118.91	-128.12	-84.01	-114.21	0
280	-125.05	-118.73	-128.15	-85.83	-114.68	0
281	-124.87	-118.63	-128.19	-87.08	-115.02	0
282	-124.69	-118.49	-128.26	-88.57	-115.41	0
283	-124.89	-118.21	-128.09	-88.96	-115.36	0
284	-125.06	-118.09	-127.91	-89.42	-115.33	0.8
285	-125.18	-117.93	-127.62	-89.99	-115.29	18.3
286	-125.24	-117.87	-127.46	-91.45	-115.24	0
287	-125.32	-117.77	-127.34	-92.55	-115.2	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
288	-125.28	-117.83	-127.26	-92.72	-115.11	0
289	-125.21	-117.88	-127.02	-92.99	-115.03	0
290	-125.16	-117.91	-126.94	-93.24	-114.86	12.3
291	-125.09	-117.94	-126.87	-93.58	-114.67	0
292	-125.05	-117.96	-126.95	-93.86	-114.56	0
293	-125.01	-117.99	-127.08	-94.18	-114.55	0
294	-124.99	-118.01	-127.18	-94.41	-114.54	0
295	-124.96	-118.04	-127.26	-94.94	-114.54	0
296	-124.94	-118.06	-127.32	-95.37	-115.39	0
297	-124.87	-118.11	-127.28	-95.63	-115.48	0
298	-124.76	-118.18	-127.22	-95.87	-115.87	0
299	-124.7	-118.23	-127.18	-96.23	-115.99	0
300	-124.66	-118.29	-127.14	-96.69	-116.22	0
301	-124.63	-118.34	-108.46	-17.97	-73.74	45.0
302	-123.93	-118.46	-116.38	-19.23	-38.95	0.3
303	-122.79	-90.86	-125.99	-21.38	-41.46	0
304	-75.05	-99.14	-100.18	-16.41	-34.53	18.8
305	-79.56	-73.32	-109.21	-11.58	-29.74	0
306	-53.67	-82.28	-71.88	-11.5	-19.62	16.3
307	-76.04	-103.99	-98.53	-11.44	-20.87	0
308	-78.89	-40.19	-33.02	-11.89	-21.79	3.5
309	-44.46	-67.53	-60.65	-12.58	-16.1	42.8
310	-67.64	-87.71	-86.62	-13.46	-20.22	0
311	-75.34	-91.69	-87.93	-23.1	-25.78	0
312	-75.81	-97.74	-89.02	-27.14	-28.49	0
313	-76.16	-98.67	-91.56	-31.32	-32.86	0
314	-76.63	-100.82	-92.25	-34.58	-36.48	0
315	-77.15	-97.89	-97.78	-40.93	-43.73	29.3
316	-50.53	-39.68	-24.61	-3.79	-15.75	37.8

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
317	-54.67	-43.06	-59.13	-10.01	-17.59	0
318	-73.39	-84.12	-85.18	-14.52	-18.73	0
319	-74.18	-88.69	-87.69	-18.61	-20.68	0
320	-75.43	-89.33	-89.33	-23.05	-23.67	0
321	-76.68	-89.69	-92.76	-29.36	-25.93	0
322	-77.21	-92.19	-94.85	-30.53	-28.91	0
323	-78.63	-100.04	-95.98	-31.06	-31.97	0.8
324	-79.36	-72.61	-97.42	-32.49	-37.26	29.3
325	-80.38	-33.24	-22.26	-4.13	-20.11	9.3
326	-38.36	-74.25	34.83	-2.89	-19.37	0
327	-69.81	-63.63	-81.85	-9.32	-18.76	8.5
328	-73.44	-72.93	-68.76	-10.52	-17.83	4.5
329	-64.39	-89.75	-78.02	-12.48	-16.78	0
330	-75.82	-94.98	-87.67	-14.96	-15.42	0
331	-76.23	-95.32	-91.70	-16.72	-16.06	0
332	-77.66	-95.87	-92.33	-26.32	-16.84	0
333	-79.03	-96.41	-93.08	-30.81	-20.77	0
334	-80.71	-96.83	-93.89	-35.23	-25.66	0
335	-82.02	-97.29	-94.92	-37.43	-37.64	0
336	-82.12	-98.48	-96.43	-39.98	-41.46	0
337	-83.68	-100.63	-98.29	-42.16	-46.91	0
338	-84.21	-101.45	-98.65	-44.54	-50.47	0
339	-85.39	-105.28	-99.08	-38.42	-44.43	6.3
340	-85.12	-104.37	-96.54	-35.79	-37.59	0.5
341	-83.22	-103.17	-94.08	-32.48	-35.13	0.8
342	-79.75	-101.85	-90.55	-19.67	-5.34	0
343	-77.51	-100.19	-93.11	-17.21	-6.03	0
344	-58.62	-68.25	-43.39	-3.55	-7.81	27.5
345	-66.24	-83.77	-82.98	-6.06	-8.92	0

(Continued)

Julian Day	Plot A (cm)	Plot B (cm)	Plot C (cm)	Plot H (cm)	Plot I (cm)	Rainfall (mm)
346	-74.33	-95.13	-85.26	-9.59	-10.12	0
347	-75.08	-96.71	-87.41	-14.18	-15.99	0
348	-75.72	-97.38	-89.81	-19.31	-23.68	0
349	-76.34	-98.84	-93.83	-22.36	-29.66	0
350	-34.74	-73.02	-38.74	-4.93	-23.12	39.0
351	-46.09	-77.12	-42.19	-5.23	-18.30	7.3
352	-70.26	-91.95	-83.94	-5.94	-5.51	0
353	-73.53	-93.89	-88.51	-8.73	-6.96	0
354	-61.90	-92.48	-63.03	-6.81	-6.63	5.3
355	-68.72	-91.39	-79.86	-5.42	-6.02	1.8
356	-70.81	-90.61	-88.69	-5.26	-5.71	0
357	-73.51	-90.87	-92.58	-4.94	-5.24	0
358	-75.49	-92.08	-77.34	-4.67	-5.20	0.8
359	-69.69	-93.89	-80.01	-5.52	-5.79	2.5
360	-73.01	-95.94	-92.33	-6.36	-6.43	0.3
361	-61.45	-89.13	-86.56	-4.83	-5.82	3.5
362	-70.22	-89.76	-75.68	-3.49	-4.05	0.3
363	-71.63	-90.48	-84.55	-4.23	-3.19	0
364	-72.87	-91.87	-91.46	-5.51	-3.72	0
365	-73.53	-93.41	-93.09	-6.44	-4.39	0
366	-74.21	-95.56	-94.21	-7.18	-4.96	0

APPENDIX B

SUMMATION OF EXCESS WATER (SEW)

Table B.1. Estimated monthly SEW_{45} (cm-days) in the experimental plots in 1991 and 1992.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
1 9 9 1													
Plot A	131.96	59.51	98.16	95.34	164.42	79.44	2.99	0.35	0.00	0.00	0.00	0.00	632.17
Plot B	119.65	93.20	59.85	63.03	142.59	0.00	1.54	0.00	0.00	0.00	0.00	0.00	479.86
Plot C	218.49	172.34	105.31	162.75	210.27	25.45	23.49	6.16	0.00	0.00	0.00	1.58	925.84
Avg	156.70	108.35	87.77	107.04	172.42	34.96	9.34	2.17	0.00	0.00	0.00	0.53	679.29
Plot H	685.29	380.93	403.26	482.61	1094.3	718.84	663.36	127.53	310.54	203.58	232.79	371.65	5674.7
Plot I	781.51	308.48	459.03	344.96	575.74	136.69	104.23	46.52	233.40	191.87	96.51	46.75	3325.7
Avg	733.4	344.70	431.14	413.78	835.03	427.76	383.80	87.02	271.97	197.72	164.65	209.20	4500.2
1 9 9 2													
Plot A	167.76	131.29	56.92	19.79	6.64	43.04	3.27	39.66	0.00	0.00	28.22	8.35	504.94
Plot B	84.96	57.72	19.00	8.52	0.80	38.96	0.00	30.34	0.00	0.00	13.15	0.00	253.45
Plot C	168.32	122.36	44.52	12.24	6.23	88.41	9.82	39.18	0.64	0.00	42.11	20.21	554.04
Avg	140.35	103.79	40.15	13.52	4.56	56.80	4.36	36.39	0.21	0.00	27.83	9.52	437.48
Plot H	930.30	920.01	755.30	340.38	119.68	675.28	312.07	99.24	119.44	66.57	456.92	894.87	5690.1
Plot I	504.18	780.14	377.78	95.62	124.41	814.00	328.42	81.03	12.58	31.26	343.11	856.37	4348.9
Avg	717.24	850.08	566.54	218.00	122.04	744.64	320.24	90.14	66.01	48.92	400.02	875.62	5019.5

Table B.2. Estimated monthly SEW_{60} (cm-days) in the experimental plots in 1991 and 1992.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1 9 9 1													
Plot A	255.17	93.91	159.62	174.89	281.31	176.56	42.70	3.13	0.00	0.00	0.84	0.13	1188.26
Plot B	207.16	155.22	110.98	117.19	229.13	2.84	12.52	0.00	0.00	0.00	0.00	0.00	835.04
Plot C	407.97	255.41	166.98	264.47	344.31	57.99	54.62	13.52	0.00	0.00	0.00	1.58	1566.85
Avg	290.10	168.18	145.86	185.52	284.92	79.13	36.61	5.55	0.00	0.00	0.28	0.57	1196.72
Plot H	1141.0	757.26	828.50	709.83	1542.4	1145.2	1041.4	197.72	549.30	279.85	465.36	763.63	9421.45
Plot I	1178.0	562.48	875.20	551.17	1012.7	487.48	420.42	96.49	553.79	308.82	293.42	326.80	6666.77
Avg	1159.5	659.87	851.85	630.50	1277.6	816.34	730.91	147.10	551.54	294.34	379.39	545.22	8044.11
1 9 9 2													
Plot A	276.13	216.41	101.84	33.61	23.44	88.63	19.11	65.49	1.20	0.00	69.42	31.04	926.32
Plot B	200.58	112.35	36.94	21.64	4.79	89.28	1.47	55.72	0.00	0.00	54.68	0.15	577.60
Plot C	281.30	201.83	80.29	23.04	17.90	162.69	26.36	65.89	7.84	0.00	81.43	50.72	999.29
Avg	252.67	176.86	73.02	26.10	15.38	113.53	15.65	62.37	3.01	0.00	68.51	27.30	834.40
Plot H	1284.9	1279.7	1206.0	727.98	205.67	1085.2	648.72	243.57	270.60	108.51	747.18	1294.2	9102.2
Plot I	846.86	1212.9	798.62	322.36	177.61	1250.0	741.86	221.18	46.33	92.48	631.41	1274.9	7616.5
Avg	1065.9	1246.3	1002.3	525.17	191.64	1167.6	695.29	232.38	158.46	100.50	689.30	1284.6	8359.4

APPENDIX C

OBSERVED BROMIDE CONCENTRATION

Table C. Observed bromide concentration (mg/L) in the drained and the nondrained plots, Ben Hur Research Farm, Baton Rouge, Louisiana.

Date of Sampling	Days After Appl'n	Drained Plots						Nondrained Plots			
		Plot A		Plot B		Plot C		Plot H		Plot I	
		1 m	2 m	1 m	2 m	1m	2 m	1 m	2 m	1 m	2 m
Mar 18	10	534.11	26.01	204.77	8.41	605.47	38.95	1448.48	25.33	664.17	117.79
Apr 15	38	295.65	41.27	92.64	13.62	1102.40	136.38	546.88	14.39	18905.85	69.39
Apr 20	43	361.40	21.55	50.58	19.25	173.12	52.73	346.51	20.63	505.57	19.25
Apr 27	50	427.55	171.72	100.99	39.14	389.40	228.73	863.44	33.05	834.60	65.33
May 1	54	5252.13	20.91	1516.26	15.84	700.14	325.38	1864.71	10.78	4234.79	15.46
May 3	56	186.47	14.81	89.11	17.83	189.37	103.48	124.47	7.73	250.86	16.57
May 6	59	5514.58	884.76	142.44	44.19	2653.02	273.28	1835.09	18.25	16267.11	57.61
May 12	65	479.58	19.53	188.28	17.36	1935.28	195.78	307.77	10.42	328.28	18.03
May 16	69	12760.24	30.11	221.57	20.32	760.30	238.24	202.83	10.88	3602.79	17.01
May 20	73	472.25	29.76	122.35	19.47	1231.86	131.43	144.98	9.29	757.44	15.05
May 31	84	5981.02	119.38	73.38	24.62	1351.03	343.88	528.83	4.72	381.60	29.55
June 7	91	5477.76	103.13	97.31	18.09	448.37	159.90	308.00	9.52	153.35	3.15

(Continued)

Date of Sampling	Days After Appl'n	Drained Plots						Nondrained Plots			
		Plot A		Plot B		Plot C		Plot H		Plot I	
		1 m	2 m	1 m	2 m	1m	2 m	1 m	2 m	1 m	2 m
June 12	96	591.01	106.75	48.73	16.64	160.46	139.42	332.71	6.19	381.48	6.23
June 19	103	1044.59	35.90	62.50	11.16	126.44	53.71	389.93	3.67	258.69	7.57
June 25	109	481.52	28.60	49.13	12.94	171.05	13.29	291.73	5.77	732.05	10.88
June 28	112	437.24	29.04	41.48	8.90	160.16	34.78	9.42	48.30	480.62	5.09
July 5	119	924.51	38.90	100.04	6.93	201.35	54.16	813.38	4.80	2942.18	5.84
July 10	124	4861.55	81.65	1039.79	50.92	231.66	43.91	4358.34	15.36	1974.69	67.61
July 28	142	2347.84	25.81	ns	47.35	685.89	325.89	1431.00	23.13	309.00	23.31
Aug 5	150	ns	47.79	ns	25.89	ns	53.33	331.14	4.13	2546.53	11.76
Aug 11	156	ns	53.32	ns	9.51	ns	51.51	371.81	10.07	713.45	23.35
Aug 29	174	ns	52.36	ns	6.99	ns	51.09	261.95	4.14	939.91	11.04
Sept 2	177	ns	53.89	ns	11.54	ns	99.16	1073.29	7.98	3500.47	14.91
Sep 27	203	ns	41.36	ns	7.38	ns	53.48	1103.29	17.16	843.82	1.81
Oct 28	234	269.54	24.35	ns	8.11	ns	25.45	896.32	9.14	199.89	24.52
Nov 22	259	199.67	22.78	ns	17.39	142.07	74.91	183.61	11.48	299.18	16.20
Dec 3	270	250.02	23.56	ns	29.33	79.13	337.90	623.26	19.44	1452.42	22.72
Dec 15	282	362.57	28.38	115.75	27.97	175.34	0.04	197.15	20.39	701.48	29.55

(Continued)

Date of Sampling	Days After Appl'n	Drained Plots						Nondrained Plots			
		Plot A		Plot B		Plot C		Plot H		Plot I	
		1 m	2 m	1 m	2 m	1m	2 m	1 m	2 m	1 m	2 m
Jan 10	308	245.53	17.09	126.96	10.77	263.27	17.63	14.00	14.39	2549.87	69.39
Jan 19	317	216.94	44.09	66.13	22.29	144.47	54.19	162.37	10.08	590.13	15.93
Feb 7	336	293.52	103.68	302.94	41.14	93.85	64.73	174.05	15.30	184.67	14.26
Feb 18	347	130.98	41.89	195.74	34.70	64.83	64.57	126.79	12.10	178.76	7.69
Mar 7	365	49.02	53.88	142.95	13.54	31.24	57.48	58.60	11.30	136.35	8.17
Apr 14	403	489.26	18.12	136.60	12.61	366.46	40.12	415.65	30.60	767.62	16.32
May 29	448	263.16	19.77	57.37	13.04	184.25	52.97	119.31	3.60	544.37	7.88
June 4	454	496.92	112.62	430.16	90.63	102.02	61.78	666.12	25.74	211.23	14.13
June 15	465	423.52	123.16	205.61	30.67	75.52	70.87	531.58	29.99	220.61	14.01
June 21	471	341.64	123.76	112.19	25.34	196.06	92.10	533.12	30.58	228.96	12.33
July 2	482	215.74	70.28	112.64	29.45	125.73	74.16	180.36	36.68	143.09	0.00
July 11	491	433.62	116.93	224.22	19.00	87.34	80.64	275.29	33.10	113.03	12.79
July 25	505	60.39	56.51	ns	11.17	92.41	55.09	108.34	19.36	57.63	7.73
Aug 27	538	216.94	44.09	66.13	22.29	144.47	54.19	162.37	10.08	59.13	15.93
Sept 4	547	ns	101.62	ns	27.56	ns	42.77	106.26	31.33	100.21	8.91
Sept 9	551	167.09	116.15	151.84	20.39	39.33	43.44	89.53	38.74	88.15	10.97

(Continued)

Date of Sampling	Days After Appl'n	Drained Plots						Nondrained Plots			
		Plot A		Plot B		Plot C		Plot H		Plot I	
		1 m	2 m	1 m	2 m	1m	2 m	1 m	2 m	1 m	2 m
Sept 22	564	ns	114.41	ns	19.76	ns	41.38	92.53	45.92	89.69	9.11
Oct 11	583	ns	114.90	ns	15.69	ns	43.05	126.57	41.54	ns	11.09
Oct 28	600	ns	119.40	ns	14.72	ns	31.96	160.02	56.40	69.09	4.38
Nov 1	604	94.92	103.96	20.88	10.92	ns	41.42	179.80	63.79	58.80	8.41
Nov 5	608	177.79	96.78	102.62	61.70	55.15	36.72	179.79	61.76	126.39	6.36

ns -- no sample collected due to deep watertable level.

APPENDIX D

AVERAGED OBSERVED BROMIDE CONCENTRATION

AND CUMULATIVE THREE-DAYS RAINFALL

Table D. Averaged observed bromide concentration (mg/L) in the drained and nondrained plots and the cumulative three-days rainfall before sample collection.

Date of Sample Collection	Julian Day	Days After Tracer Application	Drained Plots		Nondrained Plots		Rainfall (mm)
			1-m	2-m	1-m	2-m	3 dbs
Mar 18	77	10	448.12	24.46	1056.33	71.56	39.30
Apr 15	105	38	496.90	63.76	9726.36	41.89	41.80
Apr 20	110	43	195.04	31.18	426.04	19.94	43.10
Apr 27	117	50	305.98	146.53	849.02	49.19	30.00
May 1	121	54	2489.51	120.71	3049.75	13.12	97.80
May 3	123	56	154.98	45.37	187.66	12.15	30.30
May 6	126	59	2770.01	400.74	9051.10	37.93	31.50
May 12	132	65	867.71	77.56	318.03	14.23	61.80
May 16	136	69	4580.62	96.22	1902.81	13.95	21.80
May 20	140	73	608.82	60.22	451.21	12.17	39.80
May 31	151	84	2468.48	162.63	455.22	17.14	7.60

(Continued)

Date of Sample Collection	Julian Day	Days After Tracer Application	Drained Plots		Nondrained Plots		Rainfall (mm)
			1-m	2-m	1-m	2-m	3 dbs
June 7	158	91	2007.81	93.71	230.68	6.34	95.30
June 12	163	96	266.73	87.60	357.09	6.21	28.30
June 19	170	103	411.18	33.59	324.31	5.62	52.40
June 25	176	109	233.90	18.28	511.89	8.32	20.80
June 28	179	112	212.96	24.24	245.02	26.70	5.80
July 5	186	119	408.63	33.33	1877.78	5.32	59.60
July 10	191	124	2044.33	58.83	3166.52	41.48	34.40
July 28	209	142	1011.24	133.02	870.69	23.22	12.80
Aug 5	217	150	ns	42.67	1438.84	7.95	0.00
Aug 11	223	156	ns	38.11	542.63	16.71	16.60
Aug 29	241	174	ns	36.82	600.93	7.59	49.00
Sept 2	244	177	ns	54.86	2286.88	11.45	52.60
Sep 27	269	203	ns	34.07	973.56	9.48	27.30
Oct 28	301	234	89.85	19.31	548.11	16.83	60.00

(Continued)

Date of Sample Collection	Julian Day	Days After Tracer Application	Drained Plots		Nondrained Plots		Rainfall (mm)
			1-m	2-m	1-m	2-m	3 dbs
Nov 22	326	259	113.91	38.36	241.40	13.84	32.60
Dec 3	337	270	109.72	130.26	1037.84	21.08	16.10
Dec 15	349	282	217.88	18.79	449.31	24.97	13.00
Jan 10	10	308	211.92	15.16	1281.93	41.89	70.10
Jan 19	19	317	142.51	40.19	376.25	13.00	79.00
Feb 7	38	336	230.10	69.85	179.36	14.78	71.10
Feb 18	49	347	130.52	47.05	152.77	9.90	88.00
Mar 7	67	365	74.41	41.63	97.47	9.74	68.80
Apr 14	105	403	330.77	23.62	591.63	23.46	34.80
May 29	150	448	168.26	28.59	331.84	5.74	54.60
June 4	156	454	343.03	88.35	438.67	19.94	46.30
June 15	167	465	234.89	74.90	376.09	22.00	29.80
June 21	173	471	216.63	80.40	381.04	21.45	8.60
July 2	184	482	151.37	57.97	161.72	18.34	137.20

(Continued)

Date of Sample Collection	Julian Day	Days After Tracer Application	Drained Plots		Nondrained Plots		Rainfall (mm)
			1-m	2-m	1-m	2-m	3 dbs
July 11	193	491	248.39	72.19	194.16	22.95	37.50
July 25	207	505	50.93	40.92	82.99	13.55	94.80
Aug 27	240	538	142.51	40.19	110.75	13.00	70.80
Sept 4	248	547	ns	57.32	103.24	20.12	11.60
Sept 9	253	551	119.42	59.99	88.84	24.85	68.80
Sept 22	266	564	ns	58.52	91.11	27.51	12.00
Oct 11	285	583	ns	57.88	63.28	26.32	19.10
Oct 28	302	600	ns	55.36	114.56	30.39	45.30
Nov 1	306	604	38.60	52.10	119.30	36.10	35.10
Nov 5	310	608	111.85	65.07	153.09	34.06	46.30

ns- no sample collected due to deep water table.
dbs- days before sampling.

APPENDIX E

GLEAMS PESTICIDE COMPONENT MODEL SIMULATION OUTPUT

Table E.1. Abridged output of GLEAMS Pesticide Component model simulation for 1991.

G L E A M S NONPOINT SOURCE POLLUTION MODEL (PESTICIDES)
VERSION 1.8.55 MAR 1, 1990 TIFTON GA

Ben Hur Research Farm, Plot A
Baton Rouge, Louisiana
Pesticide Worksheet 1991

STARTING DATE FOR SIMULATION 91001 JULIAN DATE

ROOTING DEPTH 1100.00 MM

POROSITY (CC/CC) BY LAYER
1 0.470 2 0.470 3 0.400 4 0.400 5 0.400 6 0.400 7 0.430 8 0.430 9 0.430 10 0.430

FIELD CAPACITY (MM/MM) BY LAYER
1 0.360 2 0.360 3 0.350 4 0.350 5 0.350 6 0.350 7 0.320 8 0.320 9 0.320 10 0.320

WILTING POINT (MM/MM) BY LAYER
1 0.200 2 0.200 3 0.220 4 0.220 5 0.220 6 0.220 7 0.120 8 0.120 9 0.120 10 0.120

ORGANIC MATTER (%) BY LAYER
1 1.14 2 1.14 3 0.85 4 0.63 5 0.63 6 0.63 7 0.46 8 0.46 9 0.37 10 0.37

PESTICIDE INPUTS

SIMULATION FOR THE PERIOD 91154 TO 91365
SIMULATION FOR 1 PESTICIDES.

PEST. NO.	PESTICIDE NAME	WATER SOL. (PPM)	FOLIAR HAFLIF (DAYS)	KOC	FOLIAR RES. (UG/G)	WSHOFF FRAC.	COEFF TRANS	COEFF UPTAKE
1	Treflan	0.30	12.0	875.0	0.00	0.00	0.00	0.18

SOIL HALF-LIFE (DAYS) 1 10.00 2 46.00 3 46.00 4 46.00 5 46.00
SOIL RESIDUE (UG/G) 1 0.0500 2 0.0500 3 0.0400 4 0.0200 5 0.0000

(Continued)

MONTHLY SUMMARY FOR JUN 1991

12 STORMS PRODUCED	21.54 CM. OF RAINFALL
5 STORMS PRODUCED	6.88 CM. OF RUNOFF
30 STORMS PRODUCED	6.25 CM. OF PERCOLATION
5 STORMS PRODUCED	0.44 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	16.0284		0.1703		0.0213		16.2200	

MONTHLY SUMMARY FOR JUL 1991

10 STORMS PRODUCED	13.51 CM. OF RAINFALL
3 STORMS PRODUCED	4.18 CM. OF RUNOFF
22 STORMS PRODUCED	4.39 CM. OF PERCOLATION
3 STORMS PRODUCED	0.25 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.7876		0.0080		0.0009		0.7965	

MONTHLY SUMMARY FOR AUG 1991

10 STORMS PRODUCED	12.18 CM. OF RAINFALL
2 STORMS PRODUCED	1.73 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.21 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0023		0.0000		0.0000		0.0023	

(Continued)

MONTHLY SUMMARY FOR SEP 1991

12 STORMS PRODUCED	6.56 CM. OF RAINFALL
0 STORMS PRODUCED	0.00 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
0 STORMS PRODUCED	0.00 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

MONTHLY SUMMARY FOR OCT 1991

9 STORMS PRODUCED	10.39 CM. OF RAINFALL
1 STORMS PRODUCED	1.38 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
1 STORMS PRODUCED	0.16 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

MONTHLY SUMMARY FOR NOV 1991

8 STORMS PRODUCED	4.37 CM. OF RAINFALL
1 STORMS PRODUCED	0.23 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
1 STORMS PRODUCED	0.02 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

(Continued)

MONTHLY SUMMARY FOR DEC 1991

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9 STORMS PRODUCED	5.24 CM. OF RAINFALL
0 STORMS PRODUCED	0.00 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
0 STORMS PRODUCED	0.00 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

ANNUAL SUMMARY FOR 1991

136 STORMS PRODUCED	182.35 CM. OF RAINFALL
42 STORMS PRODUCED	57.72 CM. OF RUNOFF
179 STORMS PRODUCED	49.65 CM. OF PERCOLATION
42 STORMS PRODUCED	3.86 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	16.8182		0.1784		0.0222		17.0188	

Ben Hur Research Farm, Plot B
Baton Rouge, Louisiana
Pesticide Component Worksheet

POROSITY (CC/CC) BY LAYER
1 0.470 2 0.470 3 0.400 4 0.400 5 0.400 6 0.400 7 0.430 8 0.430 9 0.430 10 0.430

FIELD CAPACITY (MM/MM) BY LAYER
1 0.360 2 0.360 3 0.350 4 0.350 5 0.350 6 0.350 7 0.320 8 0.320 9 0.320 10 0.320

WILTING POINT (MM/MM) BY LAYER
1 0.200 2 0.200 3 0.220 4 0.220 5 0.220 6 0.220 7 0.120 8 0.120 9 0.120 10 0.120

ORGANIC MATTER (%) BY LAYER
1 1.14 2 1.14 3 0.85 4 0.63 5 0.63 6 0.63 7 0.46 8 0.46 9 0.37 10 0.37

(Continued)

PESTICIDE INPUTS

SIMULATION FOR THE PERIOD 91154 TO 91365
SIMULATION FOR 1 PESTICIDES.

PEST. NO.	PESTICIDE NAME	WATER SOL. (PPM)	FOLIAR HAFLIF (DAYS)	KOC	FOLIAR RES. (UG/G)	WSHOFF FRAC.	COEFF TRANS	COEFF UPTAKE
1	Treflan	0.30	12.0	875.0	0.00	0.00	0.00	0.18

SOIL HALF-LIFE (DAYS) 1 46.00 2 46.00 3 46.00 4 46.00 5 46.00
SOIL RESIDUE (UG/G) 1 0.0500 2 0.0500 3 0.0400 4 0.0200 5 0.0000

MONTHLY SUMMARY FOR JUN 1991

12 STORMS PRODUCED 21.54 CM. OF RAINFALL
5 STORMS PRODUCED 6.88 CM. OF RUNOFF
30 STORMS PRODUCED 6.25 CM. OF PERCOLATION
5 STORMS PRODUCED 0.43 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	16.0286		0.1664		0.0213		16.2163	

MONTHLY SUMMARY FOR JUL 1991

10 STORMS PRODUCED 13.51 CM. OF RAINFALL
3 STORMS PRODUCED 4.18 CM. OF RUNOFF
22 STORMS PRODUCED 4.39 CM. OF PERCOLATION
3 STORMS PRODUCED 0.24 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.7877		0.0079		0.0009		0.7964	

(Continued)

MONTHLY SUMMARY FOR AUG 1991

10 STORMS PRODUCED	12.18 CM. OF RAINFALL
2 STORMS PRODUCED	1.73 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.20 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0023		0.0000		0.0000		0.0023	

MONTHLY SUMMARY FOR SEP 1991

12 STORMS PRODUCED	6.56 CM. OF RAINFALL
0 STORMS PRODUCED	0.00 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
0 STORMS PRODUCED	0.00 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	R UNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

MONTHLY SUMMARY FOR OCT 1991

9 STORMS PRODUCED	10.39 CM. OF RAINFALL
1 STORMS PRODUCED	1.38 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
1 STORMS PRODUCED	0.16 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

(Continued)

MONTHLY SUMMARY FOR NOV 1991

8 STORMS PRODUCED	4.37 CM. OF RAINFALL
1 STORMS PRODUCED	0.23 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
1 STORMS PRODUCED	0.02 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

MONTHLY SUMMARY FOR DEC 1991

9 STORMS PRODUCED	5.24 CM. OF RAINFALL
0 STORMS PRODUCED	0.00 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
0 STORMS PRODUCED	0.00 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

ANNUAL SUMMARY FOR 1991

136 STORMS PRODUCED	182.35 CM. OF RAINFALL
42 STORMS PRODUCED	57.72 CM. OF RUNOFF
179 STORMS PRODUCED	49.65 CM. OF PERCOLATION
42 STORMS PRODUCED	3.75 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	16.8185		0.1743		0.0222		17.0150	

(Continued)

Ben Hur Research Farm, Plot C
Baton Rouge, Louisiana
Pesticide Component Worksheet

POROSITY (CC/CC) BY LAYER
1 0.470 2 0.470 3 0.400 4 0.400 5 0.400 6 0.400 7 0.430 8 0.430 9 0.430 10 0.430

FIELD CAPACITY (MM/MM) BY LAYER
1 0.360 2 0.360 3 0.350 4 0.350 5 0.350 6 0.350 7 0.320 8 0.320 9 0.320 10 0.320

WILTING POINT (MM/MM) BY LAYER
1 0.200 2 0.200 3 0.220 4 0.220 5 0.220 6 0.220 7 0.120 8 0.120 9 0.120 10 0.120

ORGANIC MATTER (%) BY LAYER
1 1.14 2 1.14 3 0.85 4 0.63 5 0.63 6 0.63 7 0.46 8 0.46 9 0.37 10 0.37

PESTICIDE INPUTS

SIMULATION FOR THE PERIOD 91154 TO 91365
SIMULATION FOR 1 PESTICIDES.

PEST. NO.	PESTICIDE NAME	WATER SOL. (PPM)	FOLIAR HAFLIF (DAYS)	KOC	FOLIAR RES. (UG/G)	WSHOFF FRAC.	COEFF TRANS	COEFF UPTAE
1	Treflan	0.30	12.0	875.0	0.00	0.00	0.00	0.18

SOIL HALF-LIFE (DAYS) 1 10.00 2 46.00 3 46.00 4 46.00 5 46.00
SOIL RESIDUE (UG/G) 1 0.0500 2 0.0500 3 0.0400 4 0.0200 5 0.0000

MONTHLY SUMMARY FOR JUN 1991

12 STORMS PRODUCED 21.54 CM. OF RAINFALL
5 STORMS PRODUCED 6.88 CM. OF RUNOFF
30 STORMS PRODUCED 6.25 CM. OF PERCOLATION
5 STORMS PRODUCED 0.46 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	16.0281		0.1744		0.0213		16.2238	

(Continued)

MONTHLY SUMMARY FOR JUL 1991

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10 STORMS PRODUCED	13.51 CM. OF RAINFALL
3 STORMS PRODUCED	4.18 CM. OF RUNOFF
22 STORMS PRODUCED	4.39 CM. OF PERCOLATION
3 STORMS PRODUCED	0.25 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.7876		0.0082		0.0009		0.7967	

MONTHLY SUMMARY FOR AUG 1991

---

10 STORMS PRODUCED	12.18 CM. OF RAINFALL
2 STORMS PRODUCED	1.73 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.21 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0023		0.0000		0.0000		0.0023	

MONTHLY SUMMARY FOR SEP 1991

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12 STORMS PRODUCED	6.56 CM. OF RAINFALL
0 STORMS PRODUCED	0.00 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
0 STORMS PRODUCED	0.00 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

(Continued)

MONTHLY SUMMARY FOR OCT 1991

9 STORMS PRODUCED 10.39 CM. OF RAINFALL
1 STORMS PRODUCED 1.38 CM. OF RUNOFF
0 STORMS PRODUCED 0.00 CM. OF PERCOLATION
1 STORMS PRODUCED 0.17 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

MONTHLY SUMMARY FOR NOV 1991

8 STORMS PRODUCED 4.37 CM. OF RAINFALL
1 STORMS PRODUCED 0.23 CM. OF RUNOFF
0 STORMS PRODUCED 0.00 CM. OF PERCOLATION
1 STORMS PRODUCED 0.02 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

MONTHLY SUMMARY FOR DEC 1991

9 STORMS PRODUCED 5.24 CM. OF RAINFALL
0 STORMS PRODUCED 0.00 CM. OF RUNOFF
0 STORMS PRODUCED 0.00 CM. OF PERCOLATION
0 STORMS PRODUCED 0.00 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

(Continued)

ANNUAL SUMMARY FOR 1991

136 STORMS PRODUCED 182.35 CM. OF RAINFALL
42 STORMS PRODUCED 57.72 CM. OF RUNOFF
179 STORMS PRODUCED 49.65 CM. OF PERCOLATION
42 STORMS PRODUCED 3.98 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	16.8180		0.1827		0.0222		17.0228	

Ben Hur Research Farm, Plot H
Baton Rouge, Louisiana
Pesticide Component Worksheet

POROSITY (CC/CC) BY LAYER
1 0.470 2 0.470 3 0.400 4 0.400 5 0.400 6 0.400 7 0.430 8 0.430 9 0.430 10 0.430

FIELD CAPACITY (MM/MM) BY LAYER
1 0.360 2 0.360 3 0.350 4 0.350 5 0.350 6 0.350 7 0.320 8 0.320 9 0.320 10 0.320

WILTING POINT (MM/MM) BY LAYER
1 0.200 2 0.200 3 0.220 4 0.220 5 0.220 6 0.220 7 0.120 8 0.120 9 0.120 10 0.120

ORGANIC MATTER (%) BY LAYER
1 1.14 2 1.14 3 0.85 4 0.63 5 0.63 6 0.63 7 0.46 8 0.46 9 0.37 10 0.37

PESTICIDE INPUTS

SIMULATION FOR THE PERIOD 91180 TO 91365
SIMULATION FOR 1 PESTICIDES.

PEST. NO.	PESTICIDE NAME	WATER SOL. (PPM)	FOLIAR HAFLIF (DAYS)	KOC	FOLIAR RES. (UG/G)	WSHOFF FRAC.	COEFF TRANS	COEFF UPTAKE
1	Treflan	0.30	12.0	875.0	0.00	0.00	0.00	0.18

SOIL HALF-LIFE (DAYS) 1 10.00 2 46.00 3 46.00 4 46.00 5 46.00
SOIL RESIDUE (UG/G) 1 0.0700 2 0.0700 3 0.0500 4 0.0400 5 0.0200

(Continued)

MONTHLY SUMMARY FOR JUN 1991

12 STORMS PRODUCED	21.54 CM. OF RAINFALL
5 STORMS PRODUCED	6.88 CM. OF RUNOFF
30 STORMS PRODUCED	6.25 CM. OF PERCOLATION
5 STORMS PRODUCED	0.42 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.6520		0.0072		14.1690		14.8282	

MONTHLY SUMMARY FOR JUL 1991

10 STORMS PRODUCED	13.51 CM. OF RAINFALL
3 STORMS PRODUCED	4.18 CM. OF RUNOFF
22 STORMS PRODUCED	4.39 CM. OF PERCOLATION
3 STORMS PRODUCED	0.23 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	10.7625		0.1058		0.2763		11.1447	

MONTHLY SUMMARY FOR AUG 1991

10 STORMS PRODUCED	12.18 CM. OF RAINFALL
2 STORMS PRODUCED	1.73 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.20 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0323		0.0007		0.0000		0.0330	

(Continued)

MONTHLY SUMMARY FOR SEP 1991

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12 STORMS PRODUCED 6.56 CM. OF RAINFALL
0 STORMS PRODUCED 0.00 CM. OF RUNOFF
0 STORMS PRODUCED 0.00 CM. OF PERCOLATION
0 STORMS PRODUCED 0.00 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

MONTHLY SUMMARY FOR OCT 1991

---

9 STORMS PRODUCED 10.39 CM. OF RAINFALL
1 STORMS PRODUCED 1.38 CM. OF RUNOFF
0 STORMS PRODUCED 0.00 CM. OF PERCOLATION
1 STORMS PRODUCED 0.15 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

MONTHLY SUMMARY FOR NOV 1991

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8 STORMS PRODUCED 4.37 CM. OF RAINFALL
1 STORMS PRODUCED 0.23 CM. OF RUNOFF
0 STORMS PRODUCED 0.00 CM. OF PERCOLATION
1 STORMS PRODUCED 0.02 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

(Continued)

MONTHLY SUMMARY FOR DEC 1991

9 STORMS PRODUCED	5.24 CM. OF RAINFALL
0 STORMS PRODUCED	0.00 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
0 STORMS PRODUCED	0.00 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.0000		0.0000		0.0000		0.0000	

ANNUAL SUMMARY FOR 1991

136 STORMS PRODUCED	182.35 CM. OF RAINFALL
42 STORMS PRODUCED	57.72 CM. OF RUNOFF
179 STORMS PRODUCED	49.65 CM. OF PERCOLATION
42 STORMS PRODUCED	3.64 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	11.4469		0.1137		14.4453		26.0059	

Ben Hur Research Farm, Plot I
Baton Rouge, Louisiana
Pesticide component worksheet

POROSITY (CC/CC) BY LAYER
1 0.470 2 0.470 3 0.400 4 0.400 5 0.400 6 0.400 7 0.430 8 0.430 9 0.430 10 0.430

FIELD CAPACITY (MM/MM) BY LAYER
1 0.360 2 0.360 3 0.350 4 0.350 5 0.350 6 0.350 7 0.320 8 0.320 9 0.320 10 0.320

WILTING POINT (MM/MM) BY LAYER
1 0.200 2 0.200 3 0.220 4 0.220 5 0.220 6 0.220 7 0.120 8 0.120 9 0.120 10 0.120

ORGANIC MATTER (%) BY LAYER
1 1.14 2 1.14 3 0.85 4 0.63 5 0.63 6 0.63 7 0.46 8 0.46 9 0.37 10 0.37

(Continued)

PESTICIDE INPUTS

SIMULATION FOR THE PERIOD 91168 TO 91365
SIMULATION FOR 2 PESTICIDES.

PEST. NO.	PESTICIDE NAME	WATER SOL. (PPM)	FOLIAR HAFLIF (DAYS)	KOC	FOLIAR RES. (UG/G)	WSHOFF FRAC.	COEFF TRANS	COEFF UPTAKE
1	Metribuzin	0.12	2.0	98.6	0.00	0.00	0.00	0.26
	SOIL HALF-LIFE (DAYS)	1 16.00	2 16.00	3 16.00	4 16.00	5 16.00		
2	Metolachlor	0.53	3.0	135.7	0.00	0.00	0.00	0.24
	SOIL HALF-LIFE (DAYS)	1 27.00	2 27.00	3 27.00	4 27.00	5 27.00		

MONTHLY SUMMARY FOR JUN 1991

12 STORMS PRODUCED 21.54 CM. OF RAINFALL
5 STORMS PRODUCED 6.88 CM. OF RUNOFF
30 STORMS PRODUCED 6.25 CM. OF PERCOLATION
5 STORMS PRODUCED 0.42 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	29.1381	4.78	0.1881	0.03	0.0000	0.00	29.3262	4.81
Metolachlor	126.5836	4.59	1.2803	0.05	0.0000	0.00	127.8639	4.63

MONTHLY SUMMARY FOR JUL 1991

10 STORMS PRODUCED 13.51 CM. OF RAINFALL
3 STORMS PRODUCED 4.18 CM. OF RUNOFF
22 STORMS PRODUCED 4.39 CM. OF PERCOLATION
3 STORMS PRODUCED 0.23 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	32.2030		0.0291		0.0000		32.2321	
Metolachlor	198.5730		0.7234		0.0000		199.2964	

(Continued)

MONTHLY SUMMARY FOR AUG 1991

10 STORMS PRODUCED	12.18 CM. OF RAINFALL
2 STORMS PRODUCED	1.73 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.20 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	0.0170		0.0000		0.0000		0.0171	
Metolachlor	1.6255		0.0059		0.0000		1.6314	

MONTHLY SUMMARY FOR SEP 1991

12 STORMS PRODUCED	6.56 CM. OF RAINFALL
0 STORMS PRODUCED	0.00 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
0 STORMS PRODUCED	0.00 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	0.0000		0.0000		0.0000		0.0000	
Metolachlor	0.0000		0.0000		0.0000		0.0000	

MONTHLY SUMMARY FOR OCT 1991

9 STORMS PRODUCED	10.39 CM. OF RAINFALL
1 STORMS PRODUCED	1.38 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
1 STORMS PRODUCED	0.16 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	0.0000		0.0000		0.0000		0.0000	
Metolachlor	0.0151		0.0000		0.0000		0.0152	

(Continued)

MONTHLY SUMMARY FOR NOV 1991

8 STORMS PRODUCED	4.37 CM. OF RAINFALL
1 STORMS PRODUCED	0.23 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
1 STORMS PRODUCED	0.02 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	0.0000		0.0000		0.0000		0.0000	
Metolachlor	0.0000		0.0000		0.0000		0.0000	

MONTHLY SUMMARY FOR DEC 1991

9 STORMS PRODUCED	5.24 CM. OF RAINFALL
0 STORMS PRODUCED	0.00 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
0 STORMS PRODUCED	0.00 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	0.0000		0.0000		0.0000		0.0000	
Metolachlor	0.0000		0.0000		0.0000		0.0000	

ANNUAL SUMMARY FOR 1991

136 STORMS PRODUCED	182.35 CM. OF RAINFALL
42 STORMS PRODUCED	57.72 CM. OF RUNOFF
179 STORMS PRODUCED	49.65 CM. OF PERCOLATION
42 STORMS PRODUCED	3.66 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	61.3581	10.06	0.2172	0.04	0.0000	0.00	61.5754	10.09
Metolachlor	326.7973	11.84	2.0096	0.07	0.0000	0.00	328.8069	11.91

Table E.2. Abridged output of GLEAMS Pesticide Component model simulation for 1992.

G L E A M S NONPOINT SOURCE POLLUTION MODEL (PESTICIDES)
VERSION 1.8.55 MAR 1, 1990 TIFTON GA

Ben Hur Research Farm, Plot A
Baton Rouge, Louisiana
Pesticide Worksheet 1992

STARTING DATE FOR SIMULATION 92001 JULIAN DATE

ROOTING DEPTH 1100.00 MM

POROSITY (CC/CC) BY LAYER
1 0.470 2 0.470 3 0.400 4 0.400 5 0.400 6 0.400 7 0.430 8 0.430 9 0.430 10 0.430

FIELD CAPACITY (MM/MM) BY LAYER
1 0.360 2 0.360 3 0.350 4 0.350 5 0.350 6 0.350 7 0.320 8 0.320 9 0.320 10 0.320

WILTING POINT (MM/MM) BY LAYER
1 0.200 2 0.200 3 0.220 4 0.220 5 0.220 6 0.220 7 0.120 8 0.120 9 0.120 10 0.120

ORGANIC MATTER (%) BY LAYER
1 1.14 2 1.14 3 0.85 4 0.63 5 0.63 6 0.63 7 0.46 8 0.46 9 0.37 10 0.37

PESTICIDE INPUTS

SIMULATION FOR THE PERIOD 92121 TO 92366
SIMULATION FOR 1 PESTICIDES.

PEST. NO.	PESTICIDE NAME	WATER SOL. (PPM)	FOLIAR HAFLIF (DAYS)	KOC	FOLIAR RES. (UG/G)	WSHOFF FRAC.	COEFF TRANS	COEFF UPTAKE
1	Treflan	0.30	20.0	875.0	0.00	0.00	0.00	0.18

SOIL HALF-LIFE (DAYS) 1 10.00 2 46.00 3 46.00 4 46.00 5 46.00
SOIL RESIDUE (UG/G) 1 0.0700 2 0.0600 3 0.0400 4 0.0200 5 0.0000

(Continued)

MONTHLY SUMMARY FOR MAY 1992

11 STORMS PRODUCED	7.26 CM. OF RAINFALL
3 STORMS PRODUCED	0.64 CM. OF RUNOFF
4 STORMS PRODUCED	0.40 CM. OF PERCOLATION
3 STORMS PRODUCED	0.04 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR JUN 1992

20 STORMS PRODUCED	27.81 CM. OF RAINFALL
7 STORMS PRODUCED	10.64 CM. OF RUNOFF
28 STORMS PRODUCED	6.37 CM. OF PERCOLATION
7 STORMS PRODUCED	1.00 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR JUL 1992

16 STORMS PRODUCED	16.61 CM. OF RAINFALL
3 STORMS PRODUCED	3.57 CM. OF RUNOFF
27 STORMS PRODUCED	3.93 CM. OF PERCOLATION
3 STORMS PRODUCED	0.28 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR AUG 1992

13 STORMS PRODUCED	14.38 CM. OF RAINFALL
2 STORMS PRODUCED	1.99 CM. OF RUNOFF
5 STORMS PRODUCED	0.34 CM. OF PERCOLATION
2 STORMS PRODUCED	0.20 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR SEP 1992

8 STORMS PRODUCED	9.67 CM. OF RAINFALL
2 STORMS PRODUCED	1.32 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.13 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR OCT 1992

6 STORMS PRODUCED	9.55 CM. OF RAINFALL
2 STORMS PRODUCED	0.51 CM. OF RUNOFF

(Continued)

0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.09 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR NOV 1992

10 STORMS PRODUCED	18.21 CM. OF RAINFALL
7 STORMS PRODUCED	5.18 CM. OF RUNOFF
10 STORMS PRODUCED	2.09 CM. OF PERCOLATION
7 STORMS PRODUCED	0.32 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR DEC 1992

13 STORMS PRODUCED	9.54 CM. OF RAINFALL
3 STORMS PRODUCED	2.07 CM. OF RUNOFF
25 STORMS PRODUCED	3.55 CM. OF PERCOLATION
3 STORMS PRODUCED	0.14 T/HA OF SEDIMENT

ANNUAL SUMMARY FOR 1992

140 STORMS PRODUCED	185.47 CM. OF RAINFALL
45 STORMS PRODUCED	53.11 CM. OF RUNOFF
187 STORMS PRODUCED	38.95 CM. OF PERCOLATION
45 STORMS PRODUCED	4.07 T/HA OF SEDIMENT

G L E A M S NONPOINT SOURCE POLLUTION MODEL (PESTICIDES)
VERSION 1.8.55 MARCH 1, 1990 TIFTON GA

Ben Hur Research Farm, Plot A
Baton Rouge, Louisiana
Pesticide Worksheet 1992

STORM SUMMARY

140 STORMS PRODUCED	185.47 CM. OF RAINFALL
45 STORMS PRODUCED	53.11 CM. OF RUNOFF
187 STORMS PRODUCED	38.95 CM. OF PERCOLATION
45 STORMS PRODUCED	4.07 T/HA OF SEDIMENT

(Continued)

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.8158		0.0103		0.0161		0.8423	

Ben Hur Research Farm, Plot B
Baton Rouge, Louisiana
Pesticide Worksheet 1992

STARTING DATE FOR SIMULATION 92001 JULIAN DATE

ROOTING DEPTH 1100.00 MM

POROSITY (CC/CC) BY LAYER
1 0.470 2 0.470 3 0.400 4 0.400 5 0.400 6 0.400 7 0.430 8 0.430 9 0.430 10 0.430

FIELD CAPACITY (MM/MM) BY LAYER
1 0.360 2 0.360 3 0.350 4 0.350 5 0.350 6 0.350 7 0.320 8 0.320 9 0.320 10 0.320

WILTING POINT (MM/MM) BY LAYER
1 0.200 2 0.200 3 0.220 4 0.220 5 0.220 6 0.220 7 0.120 8 0.120 9 0.120 10 0.120

ORGANIC MATTER (%) BY LAYER
1 1.14 2 1.14 3 0.85 4 0.63 5 0.63 6 0.63 7 0.46 8 0.46 9 0.37 10 0.37

PESTICIDE INPUTS

SIMULATION FOR THE PERIOD 92167 TO 92366
SIMULATION FOR 1 PESTICIDES.

PEST. NO.	PESTICIDE NAME	WATER SOL. (PPM)	FOLIAR HAFLIF (DAYS)	KOC	FOLIAR RES. (UG/G)	WSHOFF FRAC.	COEFF TRANS	COEFF UPTAKE
1	Treflan	0.30	20.0	875.0	0.00	0.00	0.00	0.18

SOIL HALF-LIFE (DAYS) 1 10.00 2 46.00 3 46.00 4 46.00 5 48.00
SOIL RESIDUE (UG/G) 1 0.0700 2 0.0600 3 0.0400 4 0.0200 5 0.0000

(Continued)

MONTHLY SUMMARY FOR JUN 1992

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20 STORMS PRODUCED	27.81 CM. OF RAINFALL
7 STORMS PRODUCED	10.64 CM. OF RUNOFF
28 STORMS PRODUCED	6.37 CM. OF PERCOLATION
7 STORMS PRODUCED	0.97 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR JUL 1992

---

16 STORMS PRODUCED	16.61 CM. OF RAINFALL
3 STORMS PRODUCED	3.57 CM. OF RUNOFF
27 STORMS PRODUCED	3.93 CM. OF PERCOLATION
3 STORMS PRODUCED	0.27 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR AUG 1992

---

13 STORMS PRODUCED	14.38 CM. OF RAINFALL
2 STORMS PRODUCED	1.99 CM. OF RUNOFF
5 STORMS PRODUCED	0.34 CM. OF PERCOLATION
2 STORMS PRODUCED	0.20 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR SEP 1992

---

8 STORMS PRODUCED	9.67 CM. OF RAINFALL
2 STORMS PRODUCED	1.32 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.12 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR OCT 1992

---

6 STORMS PRODUCED	9.55 CM. OF RAINFALL
2 STORMS PRODUCED	0.51 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.08 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR NOV 1992

---

10 STORMS PRODUCED	18.21 CM. OF RAINFALL
7 STORMS PRODUCED	5.18 CM. OF RUNOFF

(Continued)

10 STORMS PRODUCED	2.09 CM. OF PERCOLATION
7 STORMS PRODUCED	0.32 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR DEC 1992

13 STORMS PRODUCED	9.54 CM. OF RAINFALL
3 STORMS PRODUCED	2.07 CM. OF RUNOFF
25 STORMS PRODUCED	3.55 CM. OF PERCOLATION
3 STORMS PRODUCED	0.14 T/HA OF SEDIMENT

ANNUAL SUMMARY FOR 1992

140 STORMS PRODUCED	185.47 CM. OF RAINFALL
45 STORMS PRODUCED	53.11 CM. OF RUNOFF
187 STORMS PRODUCED	38.95 CM. OF PERCOLATION
45 STORMS PRODUCED	4.07 T/HA OF SEDIMENT

G L E A M S NONPOINT SOURCE POLLUTION MODEL (PESTICIDES)
VERSION 1.8.55 MARCH 1, 1990 TIFTON GA

Ben Hur Research Farm, Plot B
Baton Rouge, Louisiana
Pesticide Worksheet 1992

STORM SUMMARY

140 STORMS PRODUCED	185.47 CM. OF RAINFALL
45 STORMS PRODUCED	53.11 CM. OF RUNOFF
187 STORMS PRODUCED	38.95 CM. OF PERCOLATION
45 STORMS PRODUCED	4.07 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.8158		0.0101		0.0161		0.8421	

(Continued)

Ben Hur Research Farm, Plot C
Baton Rouge, Louisiana
Pesticide Worksheet 1992

STARTING DATE FOR SIMULATION 92001 JULIAN DATE

ROOTING DEPTH 1100.00 MM

POROSITY (CC/CC) BY LAYER
1 0.470 2 0.470 3 0.400 4 0.400 5 0.400 6 0.400 7 0.430 8 0.430 9 0.430 10 0.430

FIELD CAPACITY (MM/MM) BY LAYER
1 0.360 2 0.360 3 0.350 4 0.350 5 0.350 6 0.350 7 0.320 8 0.320 9 0.320 10 0.320

WILTING POINT (MM/MM) BY LAYER
1 0.200 2 0.200 3 0.220 4 0.220 5 0.220 6 0.220 7 0.120 8 0.120 9 0.120 10 0.120

ORGANIC MATTER (%) BY LAYER
1 1.14 2 1.14 3 0.85 4 0.63 5 0.63 6 0.63 7 0.46 8 0.46 9 0.37 10 0.37

PESTICIDE INPUTS

SIMULATION FOR THE PERIOD 92168 TO 92366
SIMULATION FOR 1 PESTICIDES.

PEST. NO.	PESTICIDE NAME	WATER SOL. (PPM)	FOLIAR HAFLIF (DAYS)	KOC	FOLIAR RES. (UG/G)	WSHOFF FRAC.	COEFF TRANS	COEFF UPTAKE
1	Treflan	0.30	20.0	875.0	0.00	0.00	0.00	0.18

SOIL HALF-LIFE (DAYS) 1 10.00 2 46.00 3 46.00 4 46.00 5 48.00
SOIL RESIDUE (UG/G) 1 0.0700 2 0.0600 3 0.0400 4 0.0200 5 0.0000

MONTHLY SUMMARY FOR JUN 1992

20 STORMS PRODUCED 27.81 CM. OF RAINFALL
7 STORMS PRODUCED 10.64 CM. OF RUNOFF
28 STORMS PRODUCED 6.37 CM. OF PERCOLATION
7 STORMS PRODUCED 1.03 T/HA OF SEDIMENT

(Continued)

MONTHLY SUMMARY FOR JUL 1992

---

16 STORMS PRODUCED	16.61 CM. OF RAINFALL
3 STORMS PRODUCED	3.57 CM. OF RUNOFF
27 STORMS PRODUCED	3.93 CM. OF PERCOLATION
3 STORMS PRODUCED	0.29 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR AUG 1992

---

13 STORMS PRODUCED	14.38 CM. OF RAINFALL
2 STORMS PRODUCED	1.99 CM. OF RUNOFF
5 STORMS PRODUCED	0.34 CM. OF PERCOLATION
2 STORMS PRODUCED	0.21 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR SEP 1992

---

8 STORMS PRODUCED	9.67 CM. OF RAINFALL
2 STORMS PRODUCED	1.32 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.13 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR OCT 1992

---

6 STORMS PRODUCED	9.55 CM. OF RAINFALL
2 STORMS PRODUCED	0.51 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.09 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR NOV 1992

---

10 STORMS PRODUCED	18.21 CM. OF RAINFALL
7 STORMS PRODUCED	5.18 CM. OF RUNOFF
10 STORMS PRODUCED	2.09 CM. OF PERCOLATION
7 STORMS PRODUCED	0.33 T/HA OF SEDIMENT

(Continued)

MONTHLY SUMMARY FOR DEC 1992

---

13 STORMS PRODUCED	9.54 CM. OF RAINFALL
3 STORMS PRODUCED	2.07 CM. OF RUNOFF
25 STORMS PRODUCED	3.55 CM. OF PERCOLATION
3 STORMS PRODUCED	0.15 T/HA OF SEDIMENT

ANNUAL SUMMARY FOR 1992

---

140 STORMS PRODUCED	185.47 CM. OF RAINFALL
45 STORMS PRODUCED	53.11 CM. OF RUNOFF
187 STORMS PRODUCED	38.95 CM. OF PERCOLATION
45 STORMS PRODUCED	4.29 T/HA OF SEDIMENT

G L E A M S NONPOINT SOURCE POLLUTION MODEL (PESTICIDES)
VERSION 1.8.55 MARCH 1, 1990 TIFTON GA

Ben Hur Research Farm, Plot C
Baton Rouge, Louisiana
Pesticide Worksheet 1992

STORM SUMMARY

---

140 STORMS PRODUCED	185.47 CM. OF RAINFALL
45 STORMS PRODUCED	53.11 CM. OF RUNOFF
187 STORMS PRODUCED	38.95 CM. OF PERCOLATION
45 STORMS PRODUCED	4.29 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.8158		0.0105		0.0161		0.8425	

(Continued)

Ben Hur Research Farm, Plot H
Baton Rouge, Louisiana
Pesticide Worksheet 1992

STARTING DATE FOR SIMULATION 92001 JULIAN DATE

ROOTING DEPTH 1100.00 MM

POROSITY (CC/CC) BY LAYER
1 0.470 2 0.470 3 0.400 4 0.400 5 0.400 6 0.400 7 0.430 8 0.430 9 0.430 10 0.430

FIELD CAPACITY (MM/MM) BY LAYER
1 0.360 2 0.360 3 0.350 4 0.350 5 0.350 6 0.350 7 0.320 8 0.320 9 0.320 10 0.320

WILTING POINT (MM/MM) BY LAYER
1 0.200 2 0.200 3 0.220 4 0.220 5 0.220 6 0.220 7 0.120 8 0.120 9 0.120 10 0.120

ORGANIC MATTER (%) BY LAYER
1 1.14 2 1.14 3 0.85 4 0.63 5 0.63 6 0.63 7 0.46 8 0.46 9 0.37 10 0.37

PESTICIDE INPUTS

SIMULATION FOR THE PERIOD 92121 TO 92366
SIMULATION FOR 1 PESTICIDES.

PEST. NO.	PESTICIDE NAME	WATER SOL. (PPM)	FOLIAR HAFLIF (DAYS)	KOC	FOLIAR RES. (UG/G)	WSHOFF FRAC.	COEFF TRANS	COEFF UPTAKE
1	Treflan	0.30	20.0	875.0	0.00	0.00	0.00	0.18

SOIL HALF-LIFE (DAYS) 1 10.00 2 46.00 3 46.00 4 46.00 5 48.00
SOIL RESIDUE (UG/G) 1 0.0700 2 0.0600 3 0.0400 4 0.0200 5 0.0000

MONTHLY SUMMARY FOR MAY 1992

11 STORMS PRODUCED 7.26 CM. OF RAINFALL
3 STORMS PRODUCED 0.64 CM. OF RUNOFF
4 STORMS PRODUCED 0.40 CM. OF PERCOLATION
3 STORMS PRODUCED 0.04 T/HA OF SEDIMENT

(Continued)

MONTHLY SUMMARY FOR JUN 1992

---

20 STORMS PRODUCED 27.81 CM. OF RAINFALL
7 STORMS PRODUCED 10.64 CM. OF RUNOFF
28 STORMS PRODUCED 6.37 CM. OF PERCOLATION
7 STORMS PRODUCED 0.94 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR JUL 1992

---

16 STORMS PRODUCED 16.61 CM. OF RAINFALL
3 STORMS PRODUCED 3.57 CM. OF RUNOFF
27 STORMS PRODUCED 3.93 CM. OF PERCOLATION
3 STORMS PRODUCED 0.26 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR AUG 1992

---

13 STORMS PRODUCED 14.38 CM. OF RAINFALL
2 STORMS PRODUCED 1.99 CM. OF RUNOFF
5 STORMS PRODUCED 0.34 CM. OF PERCOLATION
2 STORMS PRODUCED 0.19 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR SEP 1992

---

8 STORMS PRODUCED 9.67 CM. OF RAINFALL
2 STORMS PRODUCED 1.32 CM. OF RUNOFF
0 STORMS PRODUCED 0.00 CM. OF PERCOLATION
2 STORMS PRODUCED 0.12 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR OCT 1992

---

6 STORMS PRODUCED 9.55 CM. OF RAINFALL
2 STORMS PRODUCED 0.51 CM. OF RUNOFF
0 STORMS PRODUCED 0.00 CM. OF PERCOLATION
2 STORMS PRODUCED 0.08 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR NOV 1992

---

10 STORMS PRODUCED 18.21 CM. OF RAINFALL
7 STORMS PRODUCED 5.18 CM. OF RUNOFF

(Continued)

10 STORMS PRODUCED	2.09 CM. OF PERCOLATION
7 STORMS PRODUCED	0.31 T/HA OF SEDIMENT

MONTHLY SUMMARY FOR DEC 1992

13 STORMS PRODUCED	9.54 CM. OF RAINFALL
3 STORMS PRODUCED	2.07 CM. OF RUNOFF
25 STORMS PRODUCED	3.55 CM. OF PERCOLATION
3 STORMS PRODUCED	0.14 T/HA OF SEDIMENT

ANNUAL SUMMARY FOR 1992

140 STORMS PRODUCED	185.47 CM. OF RAINFALL
45 STORMS PRODUCED	53.11 CM. OF RUNOFF
187 STORMS PRODUCED	38.95 CM. OF PERCOLATION
45 STORMS PRODUCED	3.96 T/HA OF SEDIMENT

G L E A M S NONPOINT SOURCE POLLUTION MODEL (PESTICIDES)
VERSION 1.8.55 MARCH 1, 1990 TIFTON GA

Ben Hur Research Farm, Plot H
Baton Rouge, Louisiana
Pesticide Worksheet 1992

STORM SUMMARY

140 STORMS PRODUCED	185.47 CM. OF RAINFALL
45 STORMS PRODUCED	53.11 CM. OF RUNOFF
187 STORMS PRODUCED	38.95 CM. OF PERCOLATION
45 STORMS PRODUCED	3.96 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Treflan	0.8159		0.0099		0.0161		0.8419	

(Continued)

Ben Hur Research Farm, Plot I
Baton Rouge, Louisiana
Pesticide component worksheet

STARTING DATE FOR SIMULATION 92001 JULIAN DATE

ROOTING DEPTH 1100.00 MM

POROSITY (CC/CC) BY LAYER
1 0.470 2 0.470 3 0.400 4 0.400 5 0.400 6 0.400 7 0.430 8 0.430 9 0.430 10 0.430

FIELD CAPACITY (MM/MM) BY LAYER
1 0.360 2 0.360 3 0.350 4 0.350 5 0.350 6 0.350 7 0.320 8 0.320 9 0.320 10 0.320

WILTING POINT (MM/MM) BY LAYER
1 0.200 2 0.200 3 0.220 4 0.220 5 0.220 6 0.220 7 0.120 8 0.120 9 0.120 10 0.120

ORGANIC MATTER (%) BY LAYER
1 1.14 2 1.14 3 0.85 4 0.63 5 0.63 6 0.63 7 0.46 8 0.46 9 0.37 10 0.37

PESTICIDE INPUTS

SIMULATION FOR THE PERIOD 92170 TO 92366
SIMULATION FOR 2 PESTICIDES.

PEST. NO.	PESTICIDE NAME	WATER SOL. (PPM)	FOLIAR HAFLIF (DAYS)	KOC	FOLIAR RES. (UG/G)	WSHOFF FRAC.	COEFF TRANS	COEFF UPTAKE
1	Metribuzin	0.12	2.0	98.6	0.00	0.00	0.00	0.26
	SOIL HALF-LIFE (DAYS) 1 16.00 2 16.00 3 16.00 4 16.00 5 16.00							
2	Metolachlor	0.53	3.0	135.7	0.00	0.00	0.00	0.24
	SOIL HALF-LIFE (DAYS) 1 27.00 2 27.00 3 27.00 4 27.00 5 27.00							

MONTHLY SUMMARY FOR JUN 1992

20 STORMS PRODUCED 27.81 CM. OF RAINFALL
7 STORMS PRODUCED 10.64 CM. OF RUNOFF
28 STORMS PRODUCED 6.37 CM. OF PERCOLATION
7 STORMS PRODUCED 0.94 T/HA OF SEDIMENT

(Continued)

PESTICIDE LOSSES

PESTICIDE	RUNOFF G/HA	RUNOFF % APP.	SEDIMENT G/HA	SEDIMENT % APP.	PERCOLATION G/HA	PERCOLATION % APP.	TOTAL G/HA	TOTAL % APP.
Metribuzin	14.5457	2.38	0.0241	0.00	0.0000	0.00	14.5698	2.39
Metolachlor	157.0948	5.69	0.3581	0.01	0.0000	0.00	157.4529	5.70

MONTHLY SUMMARY FOR JUL 1992

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16 STORMS PRODUCED	16.61 CM. OF RAINFALL
3 STORMS PRODUCED	3.57 CM. OF RUNOFF
27 STORMS PRODUCED	3.93 CM. OF PERCOLATION
3 STORMS PRODUCED	0.27 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF G/HA	RUNOFF % APP.	SEDIMENT G/HA	SEDIMENT % APP.	PERCOLATION G/HA	PERCOLATION % APP.	TOTAL G/HA	TOTAL % APP.
Metribuzin	5.6879		0.0084		0.0000		5.6963	
Metolachlor	79.2155		0.1453		0.0000		79.3608	

MONTHLY SUMMARY FOR AUG 1992

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13 STORMS PRODUCED	14.38 CM. OF RAINFALL
2 STORMS PRODUCED	1.99 CM. OF RUNOFF
5 STORMS PRODUCED	0.34 CM. OF PERCOLATION
2 STORMS PRODUCED	0.19 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF G/HA	RUNOFF % APP.	SEDIMENT G/HA	SEDIMENT % APP.	PERCOLATION G/HA	PERCOLATION % APP.	TOTAL G/HA	TOTAL % APP.
Metribuzin	0.0872		0.0001		0.0000		0.0873	
Metolachlor	4.4071		0.0098		0.0000		4.4168	

(Continued)

MONTHLY SUMMARY FOR SEP 1992

8 STORMS PRODUCED	9.67 CM. OF RAINFALL
2 STORMS PRODUCED	1.32 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.12 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	0.0000		0.0000		0.0000		0.0000	
Metolachlor	0.1830		0.0005		0.0000		0.1835	

MONTHLY SUMMARY FOR OCT 1992

6 STORMS PRODUCED	9.55 CM. OF RAINFALL
2 STORMS PRODUCED	0.51 CM. OF RUNOFF
0 STORMS PRODUCED	0.00 CM. OF PERCOLATION
2 STORMS PRODUCED	0.08 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	0.0000		0.0000		0.0000		0.0000	
Metolachlor	0.0368		0.0002		0.0000		0.0369	

MONTHLY SUMMARY FOR NOV 1992

10 STORMS PRODUCED	18.21 CM. OF RAINFALL
7 STORMS PRODUCED	5.18 CM. OF RUNOFF
10 STORMS PRODUCED	2.09 CM. OF PERCOLATION
7 STORMS PRODUCED	0.31 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	0.0000		0.0000		0.0000		0.0000	
Metolachlor	0.0028		0.0000		0.0000		0.0028	

(Continued)

MONTHLY SUMMARY FOR DEC 1992

13 STORMS PRODUCED 9.54 CM. OF RAINFALL
3 STORMS PRODUCED 2.07 CM. OF RUNOFF
25 STORMS PRODUCED 3.55 CM. OF PERCOLATION
3 STORMS PRODUCED 0.14 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	0.0000		0.0000		0.0000		0.0000	
Metolachlor	0.0000		0.0000		0.0000		0.0000	

ANNUAL SUMMARY FOR 1992

140 STORMS PRODUCED 185.47 CM. OF RAINFALL
45 STORMS PRODUCED 53.11 CM. OF RUNOFF
187 STORMS PRODUCED 38.95 CM. OF PERCOLATION
45 STORMS PRODUCED 3.98 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	20.3207	3.33	0.0327	0.01	0.0000	0.00	20.3534	3.34
Metolachlor	240.9400	8.73	0.5137	0.02	0.0000	0.00	241.4537	8.75

G L E A M S NONPOINT SOURCE POLLUTION MODEL (PESTICIDES)
VERSION 1.8.55 MARCH 1, 1990 TIFTON GA

Ben Hur Research Farm, Plot I
Baton Rouge, Louisiana
Pesticide component worksheet

(Continued)

STORM SUMMARY

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140 STORMS PRODUCED	185.47 CM. OF RAINFALL
45 STORMS PRODUCED	53.11 CM. OF RUNOFF
187 STORMS PRODUCED	38.95 CM. OF PERCOLATION
45 STORMS PRODUCED	3.98 T/HA OF SEDIMENT

PESTICIDE LOSSES

PESTICIDE	RUNOFF		SEDIMENT		PERCOLATION		TOTAL	
	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.	G/HA	% APP.
Metribuzin	20.3207	3.33	0.0327	0.01	0.0000	0.00	20.3534	3.34
Metolachlor	240.9400	8.73	0.5137	0.02	0.0000	0.00	241.4537	8.75

VITA

The tenth child of eleven children born to Mr. and Mrs. Patricio M. Mercado of Pura, Tarlac, Philippines, the author was born on September 23, 1950. He is married to Teresita Coloma Mercado and they are blessed with three daugthers: Myla Rowena, aged 15, Anna Ruth,14, and Czarina, 11.

He started his schooling in his native province and finished his elementary in 1962. He continued his high school and undergraduate studies at G. Araneta University Foundation, Malabon, Metro Manila, Philippines and graduated his BS in Agricultural Engineering in 1972. He was awarded a gold medal for research as one of the Ten Outstanding Graduates during the Commencement. After graduation, he was employed with the Bureau of Soils, Department of Agriculture. In the same year, he took and passed the government licensure examination to practice as a Registered Professional Agricultural Engineer. He participated in several specialized training in soil and water conservation and management such as Land Resources Evaluation and Appraisal and Design of Small Water Impounding Structures sponsored by the UNDP-FAO and Land and Water Development conducted by the Egyptian International Agricultural Centre at Dokki, Cairo, Arab Republic of Egypt in 1975. He pursued his MS in Agricultural Engineering in the same university and graduated in 1984. In 1986, he was awarded a scholarship by the British Council under the Overseas Development Aid Scholarships and pursued his Master of Science in Agricultural Extension at the Agricultural Extension and Rural Development Centre of the University of Reading, United Kingdom graduating thereat in 1987. A scholarship under the World Hunger Scholarship Program awarded by the Louisiana United Methodist Churches enabled him to continue reading his Doctor of Philosopy in Engineering Science at Louisiana State University.

He is presently connected with the Department of Agriculture as Chief Agriculturist in its Regional Research Office at Region No. III, San Fernando, Pampanga 2000, Philippines.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Orlino A. Mercado

Major Field: Engineering Science

Title of Dissertation: Field Evaluation of the Movement of Agricultural Chemical Contaminants in Alluvial Soils with a Shallow Water Table

Approved:

Richard L. Bengtson
Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

October 21, 1993